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ROLE OF SOILS AND SEDIMENT IN WATER POLLUTION CONTROL PART 1. REACTIONS OF NITROGENOUS AND PHOSPHATIC COMPOUNDS WOTH SOILS AND GEOLOGIC STRATA

George W. Bailey

Federal Water Pollution Control Administration
Athens, Georgia

March 1968

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PART 1

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FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

SOUTHEAST WATER LABORATORY

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PART 1

REACTIONS OF NITROGENOUS AND PHOSPHATIC COMPOUNDS WITH SOILS AND GEOLOGIC STRATA

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MARCH 1968

U.S. DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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FOREWORD

Nitrogen and phosphorus pollutants are causing great concern in the area of water pollution control. Levels of nitrogen and phosphorus-bearing compounds in waste effluents are often high, and the effluent, when introduced directly into watercourses, lowers the water quality. A waste treatment method is needed to reduce nitrogenous and phosphatic compounds in these effluents to innocuous levels, prior to introduction into watercourses.

Soil and geological strata could serve as such a waste treatment and disposal system. The soil and underlying geological strata may be thought of as a three dimensional, anisotropic, chromatographic column capable of adsorbing and removing solutes from a percolating solution. If the interactions between different nitrogen and phosphorus forms in the effluent and soils and geological strata are known, it is possible to predict the chromatographic behavior of the "soil waste treatment system." Using such information, it would be possible to set-forth the criteria for selecting sites of "soil waste treatment systems"; similarly, it would be possible to indicate how those soils, lacking the necessary critical properties, can be modified for use as "soil waste treatment systems."

Reported herein is a literature review relating to: (1) the reactions, nature, fate, and behavior of nitrogenous and phosphatic compounds in soil and (2) the quantitative and qualitative aspects of nitrogenous and phosphatic compounds in raw and treated sewage.

A synopsis of the nature and properties of soils and a glossary of soil science terms are included, so that the reader can better understand and comprehend the subject matter and gain a better appreciation of the impact of soils and sediments on water pollution control.

ABSTRACT

Literature on the reaction, nature, fate, and behavior of nitrogenous and phosphatic compounds in soils and geologic strata have been reviewed in relation to the use of soil and geologic strata as a media for municipal and industrial disposal. The report consists of four sections which includes:

Nature and properties of soils. Principles of soil science are discussed in terms of soil forming processes; the physico-chemical, mineralogical, and biological properties; and their interrelationships.

Chemical character of sewage. The quantitative and qualitative aspects of nitrogen and phosphorus in both raw sewage and treated effluent are indicated.

Behavior of nitrogen in soils. The mobility of inorganic and organic nitrogen in soils is discussed, as well as the reaction mechanisms by which inorganic forms can be removed from percolating solutions and fixed; the factors affecting fixation, subsequent release, and degradation are also discussed.

and Behavior of phosphorus in soils. The immobile nature of phosphorus in soils compared to nitrogen and the generally high phosphorus fixation power of soil are discussed; seven factors affecting the fixation of phosphorus by soils are discussed. The fixation mechanisms for both inorganic and organic forms of phosphorus are treated in detail. A glossary of soil science terms is included. (KEY WORDS: waste treatment and disposal system; fixation mechanisms; adsorption mechanisms; movement in soils; sewage, N & P levels; soil properties; advanced waste treatment; ammonium; nitrate; phosphate.)

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INTRODUCTION

The population explosion and intense industrialization place a severe demand on society to treat and dispose of its water-borne wastes. Water and waterways can no longer be used for the disposal of untreated wastes. Research is being carried out on advanced methods of waste treatment including various physical-chemical techniques as (1) adsorption (activated carbon), (2) electrodialysis, (3) evaporation, (4) freezing, (5) foaming, (6) oxidation, (7) reverse osmosis, (8) flocculation, (9) solvent extraction, and (10) total ion exchange.

Advanced waste treatment methods and other currently used processes generally produce a waste effluent containing low levels of contaminants. However, the concentrations of these contaminants, when discharged into water courses, may still be sufficient to impair water quality, especially by promoting the growth of algae. In this respect, nitrogen and phosphorus have important effects, being nutrients used by algae.

One way to alleviate this problem is to pass the waste through soil and underlying geological strata to reduce the nitrogen and phosphorus contaminants to innocuous levels and to re-introduce the "treated" effluent into the hydrologic cycle.

For the purpose at hand, soil and geological strata may be considered as three-dimensional, anisotropic, chromatographic columns having the capability to selectively remove solutes from a percolating solution.

A vast amount of research (mainly agricultural) has been done on the identification and characterization of nitrogen and phosphorus reactions in soils. There is a complete dichotomy of purpose in the application of this research information. For agronomic purposes, the research information is used to maximize the nitrogen and phosphorus availability for plant nutrition. While, in the case at hand, the need is to maximize the unavailability of the various forms of nitrogen and phosphorus and to prevent their re-entry into water courses.

The purpose of this discourse is to determine mainly from research in soil science: (1) the extent to which nitrogen- and phosphorus-bearing compounds are retained by soils;

(2) whether this retention is independent of the chemical nature or form of the nitrogen and phosphorus compounds; (3) if dependent, what chemical forms are most effectively removed from percolating solutions; and (4) what form, if present in the waste effluent, would pass through the "soil waste treatment column" into ground water and eventually into water courses. If certain chemical forms are more effectively removed or retained, conceivably one or more steps in sewage waste treatment might be designed to concentrate the constitutents which can be effectively removed by soil and to minimize or eliminate undesirable chemical forms.

To aid the discussion of the reactions and interactions of nitrogen and phosphorus in soils, the first section is concerned with the formation, nature, and properties of the soil system and soil constituents. To aid in a better understanding of this material, a glossary of terms commonly used in soil science is included.

Most of the emphasis in the following sections is on soils. But, it should be realized that the mineral constitutents in soils are also found in sedimentary, metamorphic, and igneous rocks. Soils and strata will exhibit similar physical-chemical properties with respect to removing solutes from percolating solutions. The major difference in their ability to remove nitrogen- and phosphorus-bearing compounds is not due to difference in properties, but rather to differences in intensity and capacity factors of chemical reactions and the permeability of the substrate.

NATURE AND PROPERTIES OF SOILS

Soil Formation

A schematic representation of the sequence of soil formation can be seen in Figure 1. The country rock is broken up by physical and chemical weathering processes (Reiche, 1945). The physical and chemical characteristics of the original country rock are modified or destroyed leaving a residue. The residue or regolith is formed as indicated, by the weathering of the country rock *in situ* or through transportation and deposition by water, wind, or ice. From the upper portion of this heterogenous mass, a soil is developed.

As weathering proceeds, the soluble constituents in the regolith are leached by the drainage water, leaving secondary and detrital minerals as products (discussed in the following section). In addition, living organisms prosper, organic matter accumulates, and weathering shifts from strictly physical-chemical to biochemical and biocolloidal weathering.

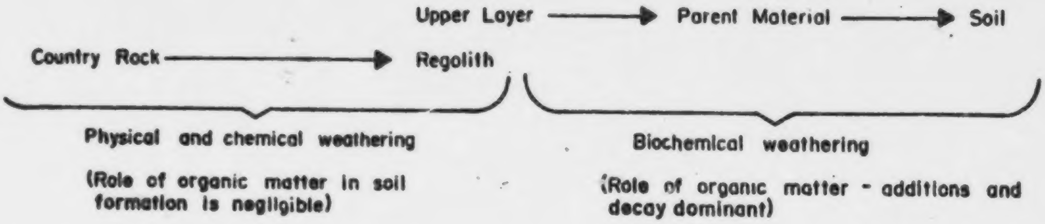

Upper Layer
Parent Material
Soil
Country Rock
Regolith
Physical and chemical weathering
(Role of organic matter in soil formation is negligible)
Biochemical weathering
(Role of organic matter - additions and decay dominant)

Figure 1. Schematic Representation of the Concept of Soil Formation

As microorganisms and higher plants prosper on the upper surface of the regolith, organic matter accumulates on and in the surface layer. At this point actual soil formation starts; a differential layering appears which can be ascribed largely to the action of living organisms. In fact, a "true" soil in the agricultural sense cannot be formed without the presence and decay of organic matter.

As weathering proceeds, horizontal layering (horizons) develops within the soil, and a "profile" which is characteristic and unique is developed (Figure 2). The "A" horizon is characterized by maximum leaching. The "B" horizon contains the maximum deposition and accumulation of clay from above. The A and B horizons together are called the solum. The C horizon or parent material has not been subjected appreciably to soil formation (Figure 2).

Forces of weathering represent a number of factors which largely control the kind of soil that finally develops. These factors are termed soil-forming factors and are:

1. Climate (particularly temperature and precipitation)
2. Living organisms (especially native vegetation)
3. Parent material (texture and structure, chemical and mineralogical composition)
4. Topography and relief
5. Time

Of these five factors, climate is the dominant one in soil formation because of its influence on the rate of physical and chemical weathering and its interactions with vegetation. Vegetative cover native to a region modifies climatic influence. Topography, through its influence on drainage, hastens or delays the climatic forces.

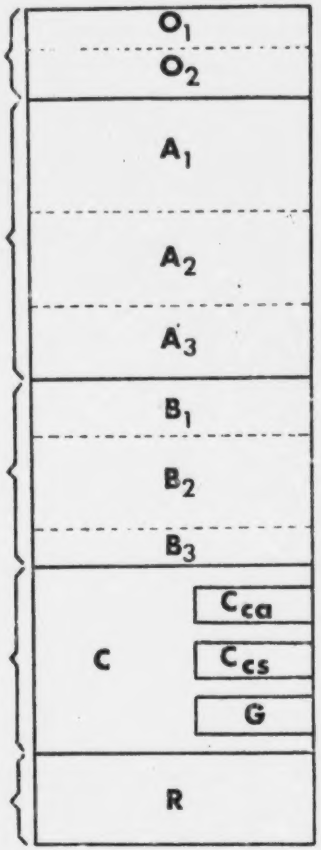
The O_1 and O_2 horizons are composed of organic matter, and rest on the A_1 horizon of unplowed soils. They are found on most unburned soils under forest vegetation and usually are absent from soils developed under grasses.

The A horizon is the zone of maximum biological activity in the mineral portion of the soil. In dry regions the A horizon is a zone in which organic matter accumulates. The same is true in humid regions where, in addition, it frequently has a clay content lower than that of the B horizon as a result of weathering and transportation of clay by water.

The B horizon includes the lower layers that have been influenced by the factors of soil formation. In soils developing on fresh geological formations no B horizon may be discernible. The same may be true occasionally in mature soils found in dry regions. Usually the B horizon is differentiated from the A horizon above and the C horizon below by color. In addition, there may be differences in structure, in content of clay, iron, aluminum, and organic matter, or a combination of all. In dry regions the B horizon frequently is distinguished from the A horizon by structure; the B horizon has a blocky or prismatic structure that is not shared by the A and C horizons. Also the organic matter content is lower in the B than in the A horizon. In cool, humid regions the B horizon is a zone of accumulation of clay, sesquioxides and organic matter moved downward in varying proportions from the A horizon. In warm, humid regions the B horizon often is relatively thick and high in content of clay and sesquioxides, showing but little evidence of accumulation from the A horizon.

The C horizon is a layer of unconsolidated material that is affected relatively little by the action of organisms. The C horizon is presumed to represent the parent material, i.e., the type of material from which at least part of the overlying horizons have developed.

The R layer is any stratum that is essentially unaffected by organisms acting in the overlying horizons and at the same time, is different from the material from which the overlying layers were formed. The R horizon is not a part of the soil profile, but it may be of significance to the overlying soil, as when the R horizon consists of consolidated rock.



The O_1 horizons consist of the original form of the vegetative matter (visible to the naked eye) corresponds to the L (litter) and some F (fermentation) layers in forest soil designations, and to the horizon formerly called Aoo.

The O_2 horizons consist of organic matter (both plant and animal matter) which cannot be recognized with the naked eye. The O_2 corresponds to the H (humus) and some F (fermentation) layers in forest soil designations and to the horizons formerly called Ao.

The A_1 horizon is dark colored, and has a relatively high content of organic matter mixed with the mineral matter. Usually it is relatively thin in soils developed under forest vegetation and thick in soils developed under grasses. Availability of plant nutrients is relatively high as a result of the surface deposition of plant residues and the activities of the soil population.

The A_2 horizon is lighter in color than the A_1 horizon and usually is lighter in color than the underlying horizon. It is the region of maximum loss of clay, iron, aluminum, or all three. This horizon usually is absent from or weakly developed in soils of dry regions, but may be strongly developed in soils of humid regions, particularly those occurring in cool climates under forest vegetation.

The A and B horizons merge through the transitional A_3 and B_1 horizons. If the B horizon is absent, the A_3 is transitional to the C horizon.

The B_2 horizon is the layer in which the maximum "B" properties are found.

The B_3 horizon is transitional to the C horizon.

The C_{ca} and C_{cs} horizons are layers of accumulated calcium carbonate and calcium sulfate found characteristically in some soils of dry regions. Commonly the C_{cs} horizon is below the C_{ca} horizon. Sometimes these accumulations are found in horizons other than the C, in which case the symbol is changed from C to B or A, as the case may be, and the subscripts remain the same.

The G horizon is a layer of intense reduction. It is characterized by the presence of ferrous iron and by a gray to olive color that commonly changes to brown on exposure to air.

Figure 2. Diagram of a Hypothetical Soil Profile Having all the Principal Horizons. (After Black, 1957, and using new Nomenclature From Glossary of Soil Science Terms)

The influence of parent material is manifested through an effect on drainage and on the chemical and mineralogical composition, and it may control, to some degree, the natural vegetation present.

Soils are grouped on the basis of their characteristics (see glossary). Zonal soils are determined primarily by the climate in which the development occurs. Intrazonal soils are those which reflect the influence of local conditions such as poor drainage, alkali salts, or some local parameter. Azonal soils are those without profile characteristics.

Mineralogical Character of Soils

Minerals in soils can be classified into two groups: (1) Primary minerals (inherited from the country rock or regolith and persisting more or less unchanged) and (2) Secondary minerals (formed by low-temperature reactions and inherited from the regolith or formed in soils by weathering).

Primary minerals in soils include quartz, feldspars, micas, amphiboles, pyroxenes, olivine, carbonates, and sulfur-bearing minerals (gypsum and pyrite). Secondary minerals include various clay minerals (kaolinite, illite, vermiculite, montmorillonite, and chlorite), iron oxides (hematite, limonite, and magnetite) and the titanium oxides (rutile and anatase).

The clay minerals are layer-lattice alumino-silicates; the layers are made up of tetrahedral sheets of silicon oxide and octahedral sheets of aluminum oxide and hydroxide. The terms, tetrahedral and octahedral, mean that the sheets are made up of four-sided and eight-sided molecular building blocks, respectively. The tetrahedral sheet (Figure 3) is composed of individual tetrahedra in which the cation silicon (and, in certain cases, aluminum) is surrounded by four oxygen anions; the octahedral sheet is composed of octahedra where aluminum (in certain cases magnesium, manganese and other cations of similar size) is surrounded by six oxygen and/or hydroxyl anions.

There are four general structural types among the clay minerals: three layer-lattice structures (1:1 type, 2:1 type, and 2:2 type) and one with a chain structure (Table 1).

1:1 Type Clay Minerals (Kaolin group)

These minerals are hydrous alumino-silicates. Kaolinite (most common member of this group) consists of a single silica tetrahedral sheet and a single alumina octahedral sheet; the two are tied together into a common sheet by shared oxygen to form the kaolin unit layer (see Figure 4). The unit layers are stacked and this constant periodicity makes up a clay crystal.

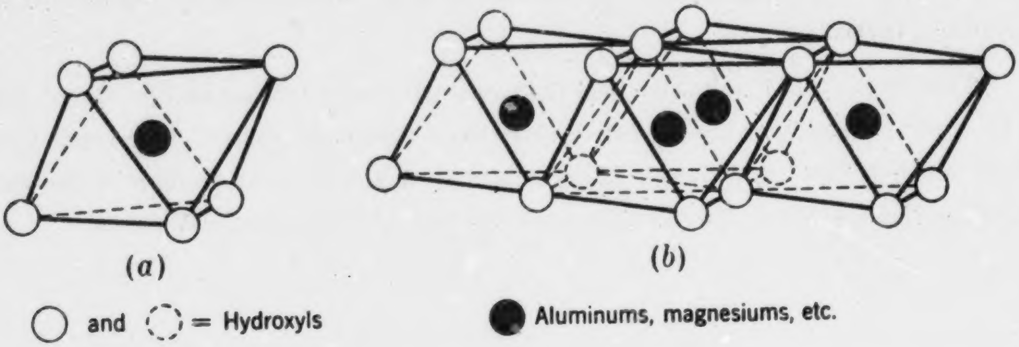


Figure 3. *A - Diagrammatic sketch showing (a) single octahedral unit and (b) the sheet structure of the octahedral units.

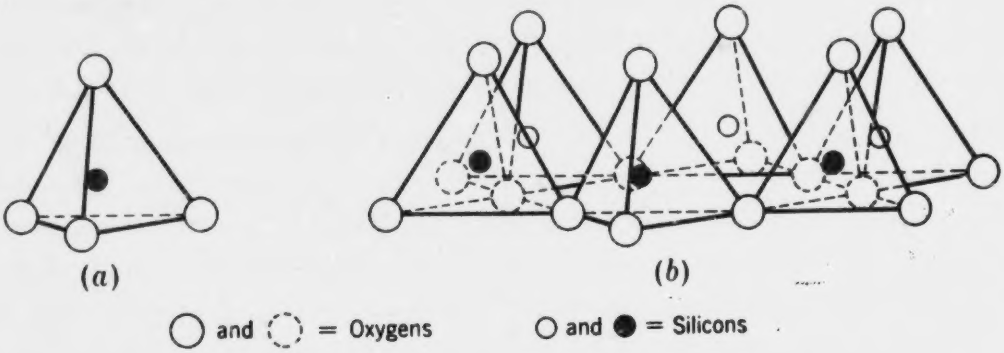


Figure 3. *B - Diagrammatic sketch showing (a) single silica tetrahedron and (b) the sheet structure of silica tetrahedrons arranged in an hexagonal network. *(From APPLIED CLAY MINERALOGY by Ralph E. Grim. Copyright (c) 1962, McGraw-Hill, Inc. Used by permission of McGraw-Hill Book Company).

Table 1. Classification of Clays

- A. Two-layer clays
  - 1. Equidimensional, kaolin
  - 2. Elongate, halloysite group
- B. Three-layer types
  - 1. Expanding lattice (along the c axis)
    - a. Equidimensional
      - (1) Montmorillonite group, full expansion
      - (2) Vermiculite, limited expansion
    - b. Elongate
      - (1) Nontronite, saponite, hectorite
  - 2. Nonexpanding lattice
    - a. Illite group
- C. Regular mixed-layer types (four-layer clays)
  - 1. Chlorite group
- D. Chain structure types
  - 1. Attapulgite, sepiolite

(After Grim, 1953)

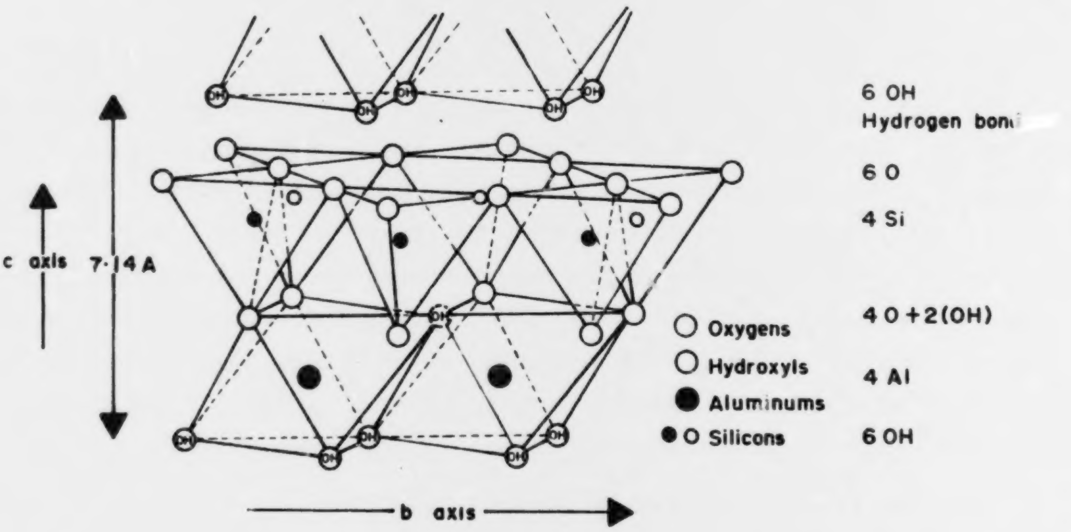


Figure 4. Diagrammatic Sketch of the Structure of Kaolinite (After Grim, 1962)

Halloysite (Figure 5) is an elongate mineral that has two forms. One form is the same as kaolinite and the other contains an added 2 H_2O.

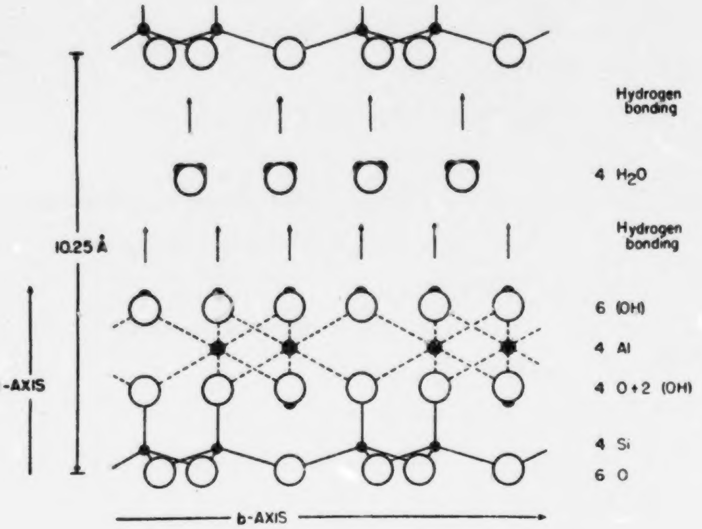


Figure 5. Diagrammatic Sketch of the Structure of Hydrated Halloysite (Endellite) (From Firman E. Bear: CHEMISTRY OF THE SOIL, New York, Reinhold Publishing Corporation, 1964)

2:1 Type Clay Minerals

Montmorillonite group. The mineral, montmorillonite, is composed of units consisting of two silica tetrahedral sheets with a central octahedral sheet (see Figure 6). The bonds between the units are weak, and water and other polar molecules can penetrate between these units and cause expansion (see Figure 6); thus, the "montmorillonites" are called the "expansible" (or swelling) clay minerals and are strong adsorbents. This expansion is perpendicular to the plane of the silicate sheets. The charge deficiency, due to isomorphic substitution (i.e., Al^{+3} for Si^{+4} in the tetrahedral layer) is balanced on the outside of the crystals by such inorganic cations as sodium, calcium, magnesium, and other cations. Approximate formulas for members of the montmorillonite group are shown in Table 2.

Vermiculite (Figure 7), also an "expansible" clay mineral, consists of layers made up of two silica tetrahedral sheets with a central magnesium-iron octahedral sheet separated by two layers of water molecules (Table 2). There is less randomness in stacking of the layers in vermiculite than in montmorillonite (Grim, 1953).

Table 2. Approximate Chemical Formulas for Various Clay Minerals

	Pseudo Mica-like Structure		
	Dioctahedral*		Trioctahedral**
Pyrophyllite	$Al_4\ Si_8\ 0_{20}\ (OH)_4$	Talc	$Mg_6\ Si_8\ 0_{20}\ (OH)_4$
	Micas		
	Diotahedral*		Trioctahedral**
Muscovite	$K_2\ Al_4\ (Si_6Al_2)\ 0_{20}\ (OH)_4$	Phlogopite	$K_2\ Mg_6(Si_6\ Al_2)\ 0_{20}\ (OH)_4$
Paragonite	$Na_2\ Al_4\ (Si_6\ Al_2)\ 0_{20}\ (OH)_4$	Biotite	$K_2\ (Mg,Fe,Al)_6\ (Si_6\ Al_2)\ 0_{20}\ (OH)_4$
Polylithionite	$K_2\ (Li_4\ Al_2)\ Si_8\ 0_{20}\ (F)_4$		
	Montmorillonite Group		
	Dioctahedral*		Trioctahedral**
Montmorillonite	$(Al_{3.34}\ \underset{\underset{Na_{0.66}}{\downarrow}}{Mg_{0.66}})\ Si_8\ 0_{20}\ (OH)_4$	Hectorite	$(Mg_{5.34}\underset{\underset{Na_{0.66}}{\downarrow}}{Li_{0.66}})\ Si_8\ 0_{20}\ (OH)_4$
Beidellite	$Al_{4.34}\ (Si_{6.34}\ \underset{\underset{Na_{0.66}}{\downarrow}}{Al_{1.66}})\ 0_{20}\ (OH)_4$	Saponite	$Mg_6\ (Si_{7.34}\ \underset{\underset{Na_{0.66}}{\downarrow}}{Al_{0.66}})\ 0_{20}\ (OH)_4$
Nontronite	$Fe_4\ (Si_{7.34}\underset{\underset{Na_{0.66}}{\downarrow}}{Al_{0.66}})\ 0_{20}\ (OH)_4$		
	Kaolinite Group		
Kaolinite	$Al_4\ Si_4\ 0_{10}\ (OH)_8$		
Halloysite	$Al_4\ Si_4\ 0_{10}\ (OH)_8\ .\ 2\ H_2O$		
Endellite	$Al_4\ Si_4\ 0_{10}\ (OH)_8\ .\ 4\ H_2O$		
	Attapulgite		
	$Mg_5\ Si_8\ 0_{20}\ (OH_2)_4\ (OH)_2\ .\ 4\ H_2O$		

*Dioctahedral members have trivalent cations in octahedral layers; 2/3 of cation sites are filled.
**Trioctahedral members have divalent cations in octahedral layers; all cation sites are filled.

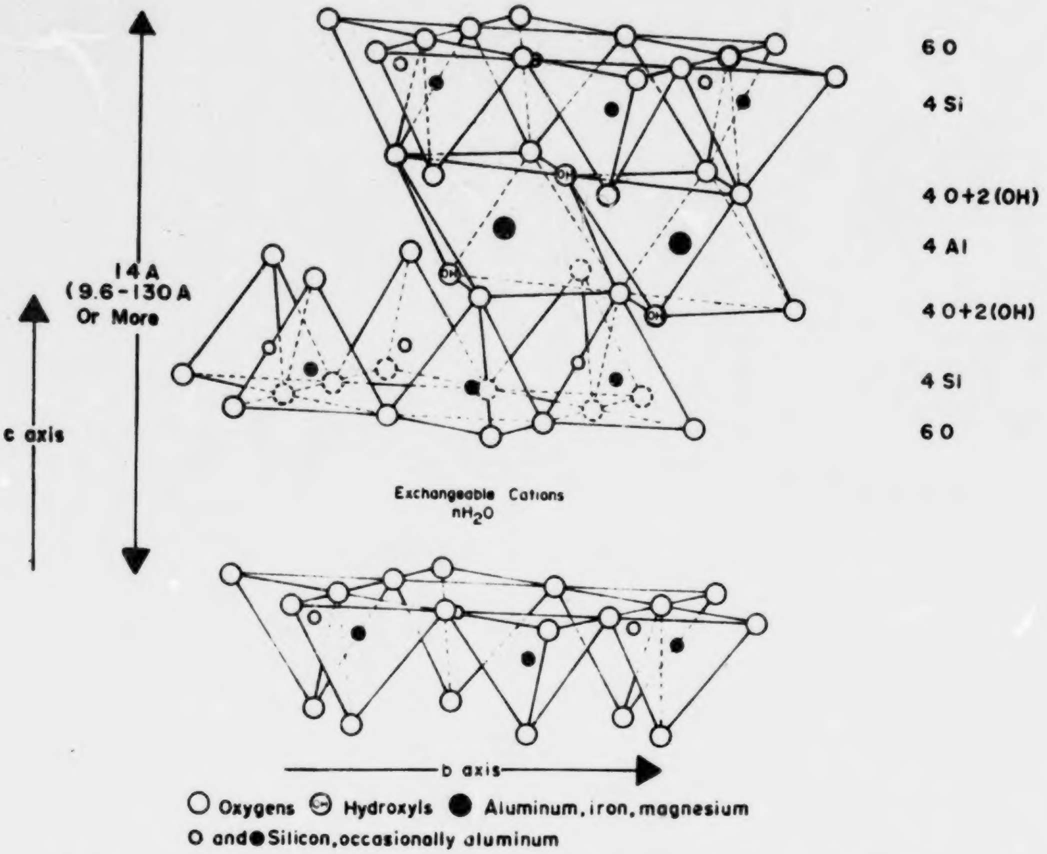


Figure 6. Diagrammatic Sketch of the Structure of Montmorillonite (After Grim, 1962)

Mica Group. Illite is the general term (Grim et al., 1937) for mica-like clay minerals. The basic structural unit is a layer composed of two silica tetrahedral sheets and a central octahedral sheet. This unit is similar to that of montmorillonite except that the charge deficiency is balanced by potassium ions which act as a bridge between the unit layers binding them together and preventing expansion or swelling (Figure 8). Illite differs from the primary mineral muscovite in the following ways: (1) less substitution of aluminum for silicon in the tetrahedral layer; (2) potassium ions which normally bind the unit layers together in the case of muscovite may be partially replaced by other cations (e.g., hydrogen); (3) contains more structural water; (4) some randomness in the stacking of the silicate layer; and (5) particle size is generally smaller.

2:2 Type Clay Minerals (Chlorite group)

True chlorite consists of alternate mica layers (two silica tetrahedral sheets and one octahedral sheet) and brucite layers (such layers may be either magnesium, aluminum, or iron hydroxides; or a combination of all three) as shown in Figure 9.

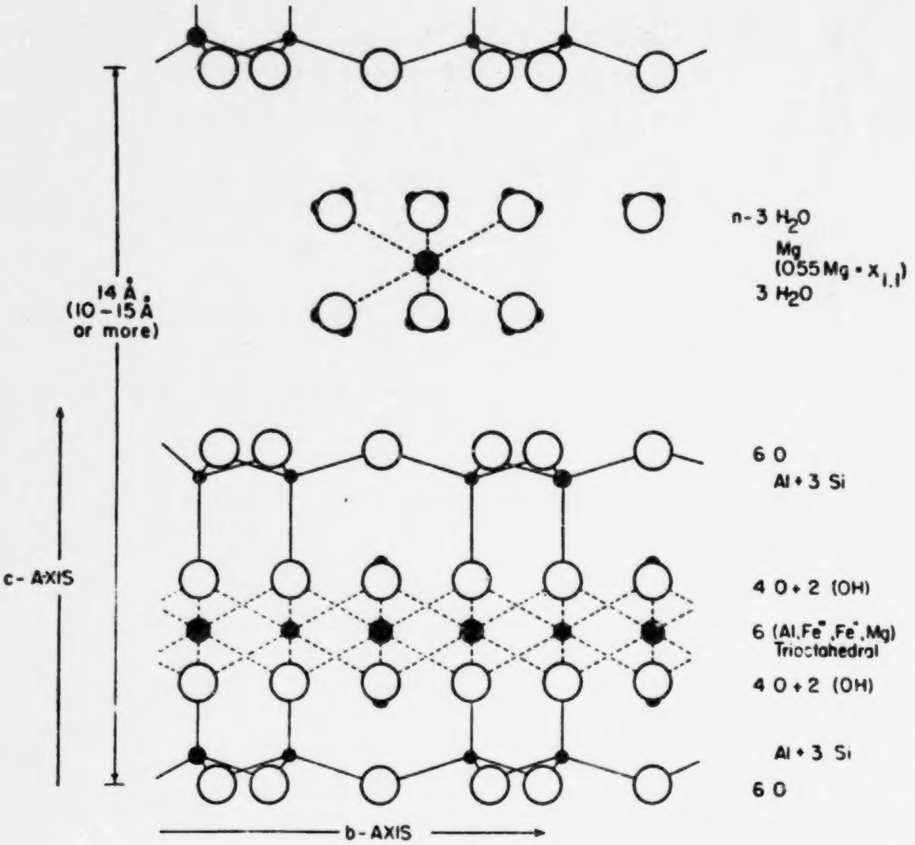


Figure 7. Diagrammatic Sketch of the Structure of Vermiculite (From Firman E. Bear: CHEMISTRY OF THE SOIL, New York, Reinhold Publishing Corporation, 1964)

Vermiculite-chlorite series: Structurally, this type of mineral has a unit layer of two silica tetrahedral sheets and an octahedral sheet and, in addition, in the interlamellar position hydroxy-aluminum ions or polymers of yet undefined composition.

Chain Structures

In general, these minerals consist of a double silica chain linked together by octahedral groups of oxygens and hydroxyls containing magnesium and aluminum. The linked chains form a kind of double-ribbed sheet. The ribbed sheets are held together by aluminum and/or magnesium ions in octahedral coordination between the apices (oxygens) of successive sheets (Figure 10). Chains of water molecules run parallel to the c axis and fill the interstices between the amphibole chains (Grim, 1953).

The characteristics of the main groups of crystalline clay minerals are summarized in Table 3.

Table 3. Major Characteristics of Main Groups of Crystalline Clay Minerals

	Two-layer Clays 1:1	Three-layer Clays 2:1	
		Non-expanding lattice	Expanding lattice
Group members	Equidimensional: kaolinite, dickite, nacrite Elongate: halloysite	illite, biotite muscovite	Equidimensional: montmorillonite, sauconite, beidellite vermiculite Elongate: nontronite, saponite, hectorite.
Structure	Rigid lattice, unit cell composed of one silica tetrahedra layer for each alumina octahedra layer	Rigid lattice, Unit cell composed of 1 silica tetrahedra layer, 1 alumina octahedra layer, 1 silica tetrahedra layer. K bonds plates together	Lattice expanding and contracting with water content or dielectric. Unit cell composed of 1 silica tetrahedra layer, 1 alumina octahedra layer, 1 silica tetrahedra layer.
Swelling and shrinking	Very little	Little	Much
Basic empirical formula	$2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$	$4SiO_2 \cdot Al_2O_3 \cdot nH_2O$ nK	$4SiO_2 \cdot Al_2O_3 \cdot nH_2O$
SiO_2/R_2O_3	1.95 - 2.02	2.16 - 3.20	4.18 - 6.00
Ionic (isomorphic) substitution in lattice	None	Al for Si	Al for Si Mg, Fe, Mn, Ti for Al
Absorptive capacity for inorganic and organic ions, water, gases, vapors.	Small	Intermediate	Large
Negative charge on layer per Unit cell	None	2(muscovite, paragonte, biotite) 1.2 or more illites	1.4 - 0.9 Verm. Mont. 1.0 - 0.6
Cation exchange capacity (charge)	3-15 me/100g. (kaolinite & halloysite $\cdot 2H_2O$) halloysite $\cdot 4H_2O$ 10-40 me/100 g.	10-40 me/100 g.	80-150 me/100 g.
Stabilization aqueous suspension	Low	Intermediate	Great
Heat of wetting	1 - 2 cal./g.	Around 4 cal./g.	10-20 cal./g.
Specific Surface	7 - 30 m.^{2}/g.	65 - 100 m.^{2}/g.	600 - 800 m.^{2}/g.
Basal spacing, repeat thickness with ethylene glycol	7.2 Å.	10 Å.	Montmorillonite 17 Å. Vermiculite 14 Å.

(After Kohnke, 1963)

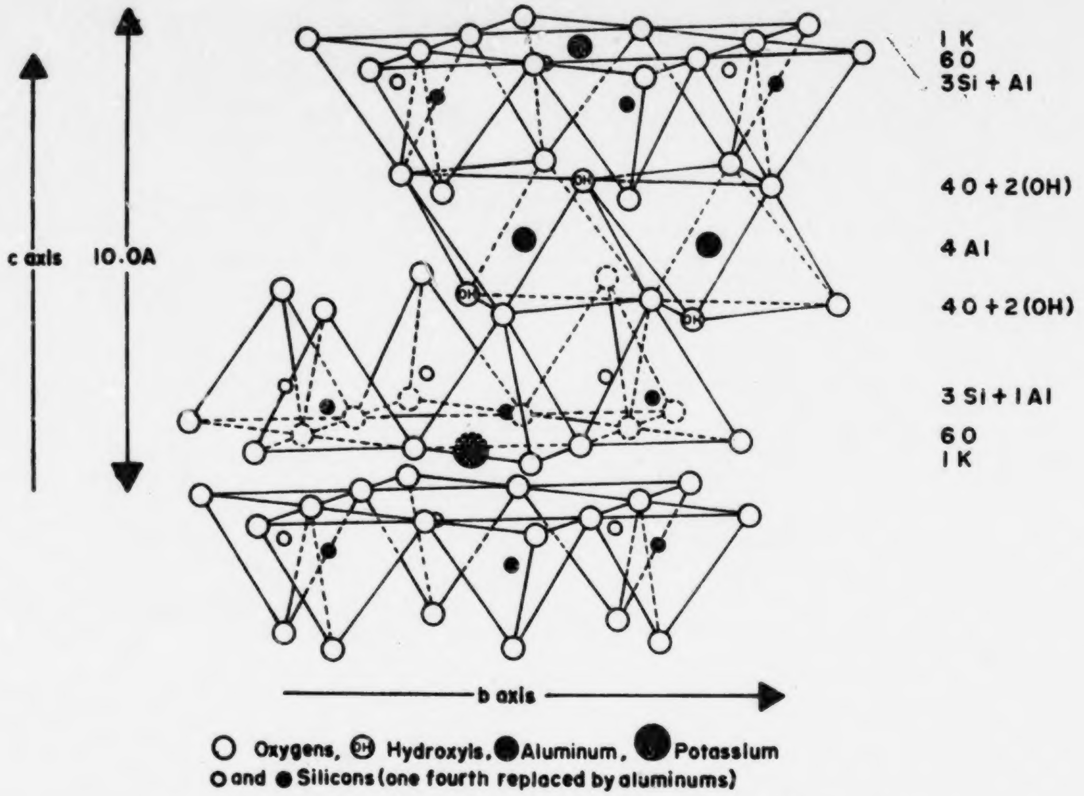

1 K
6 O
3Si + Al
4 O + 2(OH)
4 Al
4 O + 2(OH)
3 Si + 1 Al
6 O
1 K
c axis
10.0A
b axis
Oxygens, OH Hydroxyls, Aluminum, Potassium
and Silicons (one fourth replaced by aluminums)

Figure 8. Diagrammatic Sketch of the Structure of Muscovite (After Grim, 1962)

Physico-chemical Properties of Soil Constituents

The properties of soils are due principally to the properties of the colloidal (inorganic and organic) fraction. In essence, the properties of colloids depend on their surface properties. In the inorganic colloidal fraction, the clay minerals plus the amorphous and crystalline oxides and hydroxides are the principal components that determine the properties of soil systems. In the organic fraction, the humus constitutes the most important colloidal constituent.

For clarification, the two major classes of hydrous colloids are hydrophobic and hydrophilic colloids. In the past, a hydrophobic colloid was defined as a colloid which exhibited an aversion to water; a hydrophilic colloid displays an affinity for water. However, now hydrophilic colloids are called macromolecular colloids or polyelectrolyte solutions. Their colloidal properties are due to a liquid dispersion of large-size and small-size molecules; these colloids are considered as two-phase systems characterized by large interfacial areas.

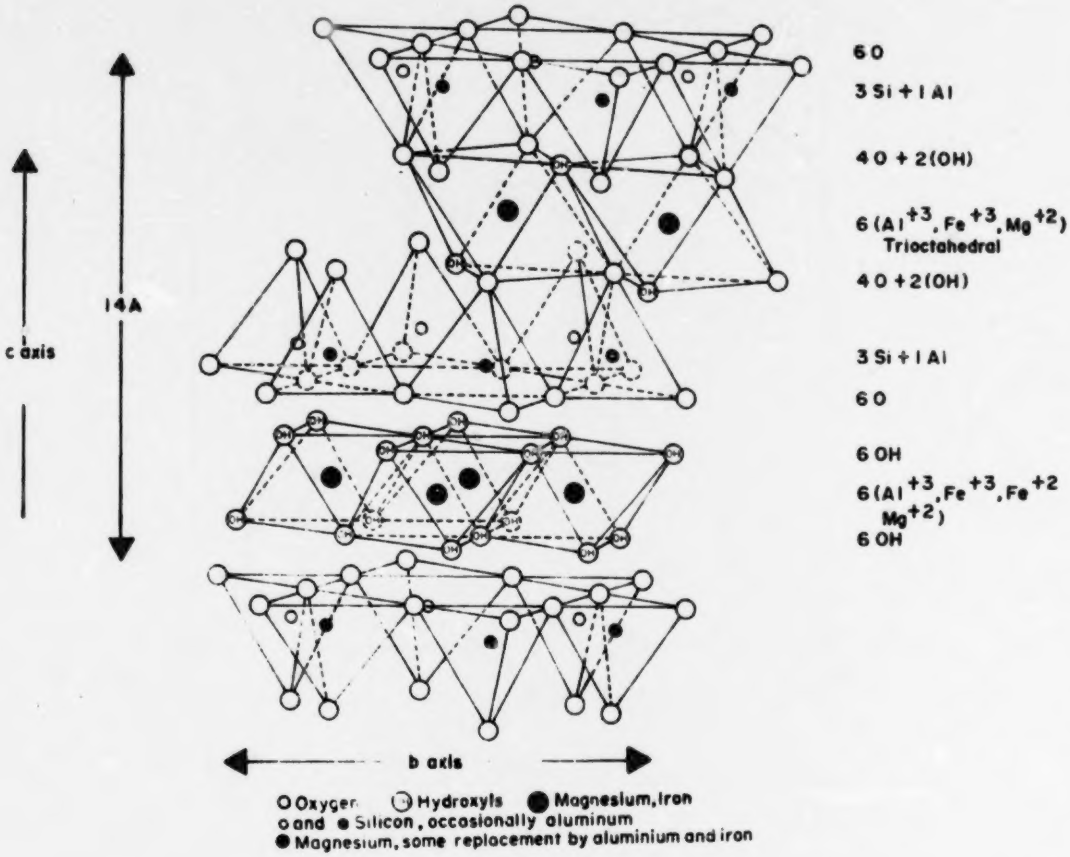


Figure 9. Diagrammatic Sketch of the Structure of Chlorite (After Grim, 1962)

Practical differences between the two colloids are that hydrophobic colloids or sols are very sensitive to the addition of salts, while macromolecular sols are insensitive toward salts, and in the true sense of the word do not flocculate as do hydrophobic sols.

Surface Chemical Phenomena

Two major phenomena, adsorption and the electrokinetic behavior, influence the surface properties of the colloids. The reader is referred to the article by Bailey and White (1964) for a more detailed explanation of the phenomena of adsorption and for a discussion of those factors affecting the adsorption of organic materials by soils and soil constituents.

Colloidal materials act as adsorbent for gases, liquids, and suspended solids in liquids. In general, there are two forms of adsorption: ion exchange and molecular adsorption. Molecular adsorption includes adsorption of polar organic molecules and adsorption of water (or wastewaters) by clay minerals.

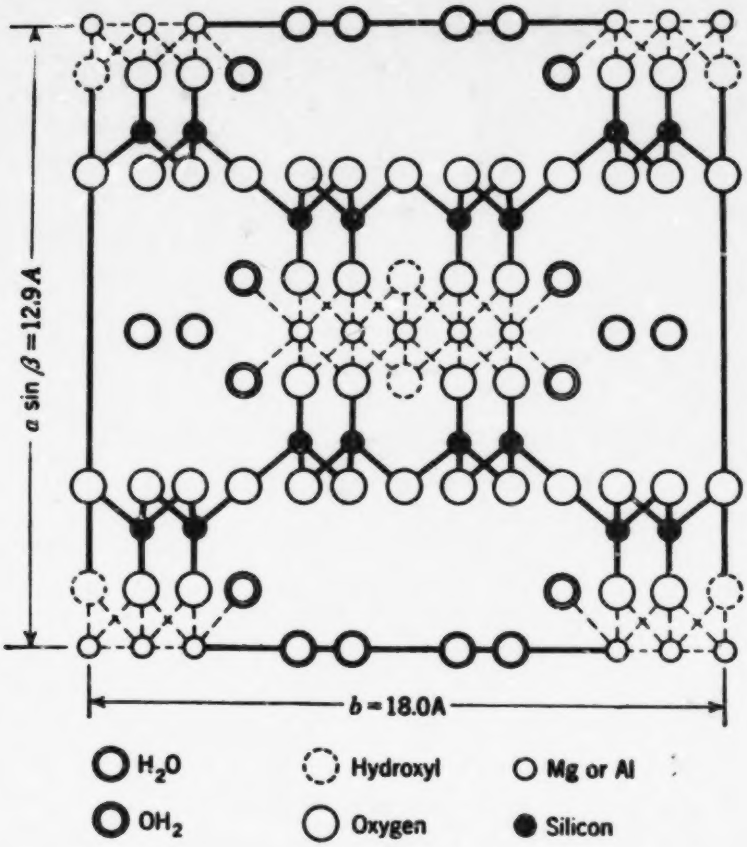


Figure 10. Schematic Presentation of the Structure of Attapulgite (From APPLIED CLAY MINERALOGY by Ralph E. Grim. Copyright (c) 1962, McGraw-Hill, Inc. Used by Permission of McGraw-Hill Book Company)

Additional information on the nature of complexes between clay minerals and organic molecules is included in works by Bradley (1945), MacEwan (1946), Grim (1953), MacEwan (1960), and Eitel (1964) and in the section on swelling properties of clays and soil systems.

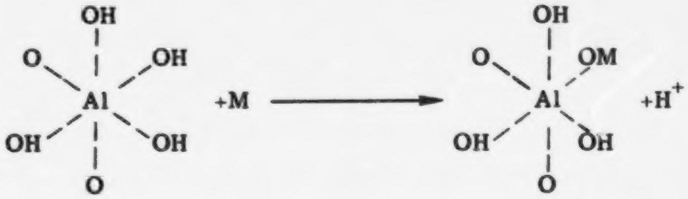
Ion Exchange. Ion exchange is probably the most important property of the soil colloidal system because the ions affect most of the other properties of the colloidal system. Clay minerals and other colloidal materials can undergo two types of ion exchange--cationic and anionic adsorption or exchange.

Cation Exchange (Cationic Adsorption). Cation exchange capacities of colloids are due principally to three causes (Grim, 1953, 1962):

(1) Isomorphic substitution in the lattice (Al^{+3} for Si^{+4} in the tetrahedral layer and Mg^{+2} for Al^{+3} in the octahedral sheet). Eighty percent of the cation exchange capacity of the clay minerals, montmorillonite and vermiculite, is due to this cause.

(2) Broken bonds around the edges of the silica-alumina units. Particle size affects the number of broken bonds, and cation exchange capacity increases with decreasing particle size. Broken bonds are the major factor responsible for the exchange capacity of the kaolin group and are important for the illite, chlorite, and attapulgite-sepiolite groups. For the clay minerals, montmorillonite and vermiculite, broken bonds contribute approximately 20% (thus a relatively small proportion) of the cation exchange capacity.

(3) The hydrogen of exposed hydroxyls, around the edges of the unit layers, may be exchanged by a cation (M).



The position and proximity of exchangeable cations on the mineral surface vary among mineral types and ions. In clay minerals whose exchange capacity results from broken bonds, the exchangeable cations are held around the edges of the crystals, [(although the work of Weiss (1964) on kaolinite raises some question about this generally accepted fact)]. In those minerals whose exchange capacity results mainly from isomorphic substitution, the cations are held mainly on the interlamellar surfaces. In any system, the positions of all the exchangeable cations with respect to the silicate surface is not the same, and even the relative positions of all the same sort of cations are not the same; certain cations are in closer proximity to the clay surface than the others will be. Marshall (1964), indicates that the percent ionization of the cation varies with the particular clay mineral, the amount of water, the nature of the cation (valency and ionic size), and the relative concentration of the cations. Different cations are held to a given clay mineral with different bonding energies, the magnitudes of which depend in part on the position of the adsorbed cation on the clay mineral surface.

The rate of cation exchange varies with the clay mineral type, the concentration of the cations, and the nature and concentration of anions. Reaction for kaolinite is essentially instantaneous; the rate is much slower for montmorillonite and attapulgite and even much slower for illite. One reason for the slower rate of reaction is that, in the case of three-layer clay minerals, diffusion into the interlamellar spaces is the rate-limiting step, while in the case of kaolinite the exchange occurs at the edges.

There is no universal lyotropic replaceability series. The series varies depending on the experimental conditions, cations involved, and the nature of the clay mineral. Cation replaceability is of vital importance, and it influences to a great extent the macro-physical properties of the system.

Five factors have been found (Grim, 1953) to be important in the replaceability of cations.

(1) Effect of cation concentration--increased concentration of the replacing cation causes greater exchange by that cation. This would be expected since cation exchange is a stoichiometric reaction and the law of mass action would be expected to hold true.

(2) Population of exchange positions--replaceability depends in part on the nature of the complementary ions populating the remainder of the exchange sites and also on the degree to which the replaced ions saturate the exchange spots.

(3) Nature of the anion in the replacing solutions affects replaceability of the cation.

(4) The nature of the ion--the valence, ionic size, and the polarizability of the ion influence the ease by which ions are replaced. In general, the higher the valence of the ion, the greater its replacing power, and the more difficult it is to displace when present on the clay.

(5) Nature of clay mineral--a separate replaceability series exists for the various types of clay minerals.

The type and amount of clay minerals present, the nature of the ion present (ionic size, valence, etc.), and the population properties of the ions on the exchange sites determine and govern (the properties of clays and thus) the properties of soils.

Since the kinds and amounts of clay minerals and the quantity and nature of organic matter vary among soils, the cation exchange capacity varies among soils. A rough correlation exists between the cation exchange capacity, texture, and organic matter content. As the soil texture becomes finer (sands → loams → clay loams), the exchange capacity increases. Finer textured soils contain more clay and generally more organic matter than coarser-textured soils.

Knowledge of the exchange capacity of a soil is not sufficient to predict the properties of that soil; in addition, the percent base saturation of the colloidal complex of the soil must be known. Thus, the amount of exchangeable base (Ca, Mg, K, etc.) and exchangeable acidity must be known. A correlation exists between percentage base saturation and pH of a soil. As the percent base saturation is reduced, the pH is reduced in a similar proportion. As a rule of thumb for soils with a pH range of 5 to 6 in humid-temperate regions, a 5% change in base saturation occurs for each 0.10 change in pH.

Anion Exchange (Anionic Adsorption). Relatively little is known about the anion exchange by soil clays. Most of the information has been on the interaction of the phosphate anion with soils and soil constituents. Other important anions are sulfate, chloride, fluoride, molybdate, and silicate. Data indicate that an average ratio of cation- to anion-exchange capacity is about 0.5 for kaolinite, 2.3 for illite, and 6.7 for montmorillonite (Grim, 1962).

Electrokinetic Properties. The electrokinetic properties of a mineral arise from: (1) the release of ions from the surface of a solid particle into a liquid; (2) the adsorption of ions from a liquid; (3) the adsorption of polar molecules on the surface of the particle; and (4) substitution of atoms of differing valence in the lattice.

In the case of clay-water systems, property (4) is the predominant factor affecting charge density on the silicate surface. This charge density at the surface produces a difference in electrical potential between the surface and the bulk solution. To maintain electrical neutrality of the system, the surface charge is balanced by an exactly opposite charge in the liquid phase. These adsorbed ions form a diffuse cloud at a finite and variable distance from the solid interface. These ions in the outer layer participate in exchange reactions and are called counter-ions.

Together, the adsorbed or fixed layer on the solid surface and the outer layer of ions in the liquid phase are known as the electrical double layer. Detailed information on the electrical double layer is available in works by MacInnes (1939), Verwey and Overbeek (1948), van Olphen (1963), Marshall (1964), and Sennett and Oliver (1965).

The four general methods of determining the electrokinetic potential of a colloidal system are: electro-osmosis, electrophoresis, sedimentation potential, and streaming potential. The property to be measured and the nature of the mobile phase are given in Table 4.

Using the proper assumptions, it is possible to calculate (using one of the four electrokinetic phenomena) the electrokinetic potential or zeta potential. Zeta potential (van Olphen, 1963) is the electric potential in the double layer at the interface between a particle which moves in an electric field and the surrounding liquid; the more negative the zeta potential the greater the degree of repulsion or, in other words, the more disperse is the system. It should be realized that the zeta potential is not the true potential at the surface of the particle, but is the potential at the shear plane between the bulk liquid and the envelope of water which moves with the particle and therefore represents the electrical potential at an unknown distance from the surface in the double layer.

The double layer theory has been used to explain the stability of colloidal dispersions (dispersive or flocculated in nature) and nature of clay-water systems.

Nature of Clay-Water Systems

Since the nature of the low-temperature water (water held by clays up to a temperature of 100-150° C) and the factors that control its character, in essence, determine such physical properties as plasticity, cohesion, bonding, compaction, suspension, and shear strength, a brief statement concerning the nature of this system is relevant to the discussion at hand. For an extended treatment and/or review the reader is referred to such works as Grim (1953, 1962); Low (1961); and Eitel (1964).

Table 4. Methods of Determining Electrokinetic Potential

Name of Procedure	Property Measured	Mobile Phase
Electro-osmosis	Velocity pressure	Liquid None
Electrophoresis	Particle mobility	Particle
Sedimentation Potential Streaming Potential	Potential	Liquid

(After Sennett and Oliver, 1965)

Although there is a great diversity of opinion concerning many aspects of the clay-water system, there is complete agreement on one fact--that the water in close proximity to the silicate surface has properties different from those of pure water. One major contention concerns the density of the adsorbed water. Tscapek (1934), as cited by Grim (1953), found that the density of adsorbed water was greater than that of bulk water (density of pure water = 1). DeWit and Arens (1950) obtained density values less than one. Low and coworkers (Hemwall and Low, 1956; Anderson and Low, 1958; Low and Anderson, 1958a, 1958b; Low, 1960a, 1960b; Kolaian and Low, 1962; Low, 1962; Miller and Low, 1963; Oster and Low, 1964) made an exhaustive study of the nature of water in clay-water systems. Their results clearly indicated that water close to the clay surface has a lower density and a higher viscosity than that of pure water and exhibits non-Newtonion behavior at low hydraulic gradients. Low (1960b) proposed that the water close to the clay surface has a more ordered structure than that of pure water, i.e., a quasi-crystalline structure. More discussion on this hypothesis is in the review article by Low (1961).

PHYSICAL PROPERTIES OF SOILS

The physical properties of soils include particle-size distribution, particle density, bulk density, pore space, structure, plasticity, shrinkage and cohesion, swelling, and flocculation.

Particle-Size Distribution

Physically, a mineral soil is a porous aggregate of inorganic particles with an admixture of decaying organic matter. Inorganic particles vary widely in size from those easily discernible with the naked eye (stone, gravel, and sand) to those requiring the use of the electron microscope to discern their morphology.

The various particle-size groups are called "separates." The two most widely accepted methods for determining the particle-size distribution are the pipette method and the Bouyoucos hydrometer method (Baver, 1948; Black et al, 1964).

To define the proportion of the various sizes present, the term "texture" is used. The various textural or soil classes are in the glossary.

The physical nature of the three major separates (sand, silt, and clay) varies drastically. Sand particles, when not coated with clay or silt, exhibit essentially no plasticity and cohesion. As a consequence of the large size of the spaces between the particles, a high percolation rate, a low water-holding capacity, and aeration is accelerated.

Clay particles exhibit nearly the opposite properties of sand: High plasticity, cohesion, high water-holding capacity, slow water and air movement. Clay, defined as a particle size, has an equivalent spherical diameter less than 2 microns (0.002 mm).

The silt separate possesses some plasticity, cohesion, and adsorption, but to a much lesser degree than does the clay separate.

The effects of particle size on such properties as surface-area, adsorptive capacity, swelling, plasticity and cohesion, and heat of wetting are shown in Figure 11. These properties increase exponentially as the particle size decreases.

Particle Density

The particle density (mass/unit volume of soil solids) of an average arable surface soil ranges from 2.60 and 2.75, this is the range for such predominant minerals as quartz, feldspars, and the colloidal alumino-silicates; the average is 2.65. Organic matter markedly reduces the average value due to its lower particle density; surface arable soils exhibit a higher organic matter content and may have a particle density of 2.4 or below.

Bulk Density

Bulk density (mass/unit volume of dry soil) includes the total soil space (space occupied by solids and pore space combined). Therefore, the bulk density of any soil is determined by the density and arrangement of the particles and reflects the status of the soil structure. Bulk densities of clay, clay loam, and silt loam surface soils range from 1.00 to 1.60 grams/cm^3; sandy loams vary from 1.20 to 1.80 grams/cm^3.

Pore Space

Pore space is that part of the soil occupied by air and water. The amount of pore space is determined largely by the structural condition of a soil, i.e., the interaction of texture, compaction, and aggregation. Pore space measurements therefore indicate how porous a soil is to water and air. The size (and degree of interconnection) of the individual spaces rather than the combined volume are of major importance.

Structure

Soil structure refers to the gross over-all aggregation or arrangement of soil solids. Soil structure often varies from horizon to horizon. Since soil structure influences such soil properties as heat transfer, water movement, aeration, bulk density, and porosity, and since the soil structure may vary from horizon to horizon, these properties can be expected to vary within a soil profile as well as between soils of different textural classes.

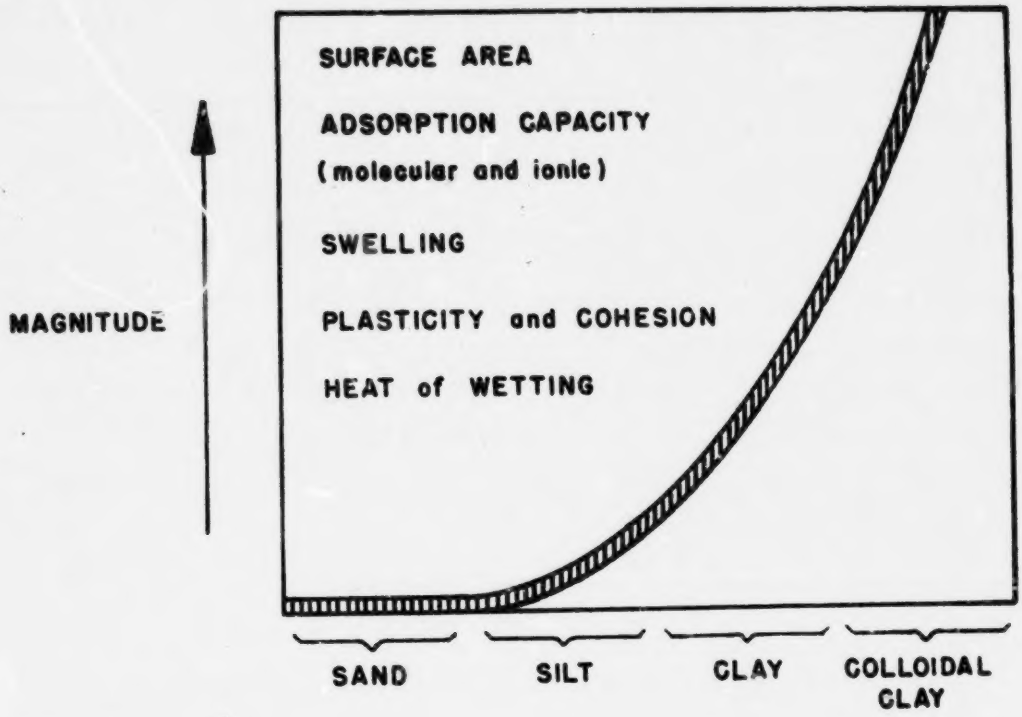


Figure 11. Particle Size Effect on the Relative Magnitude of Selected Soil Properties (After Lyon, Buckman, and Brady, 1952)

Plasticity

Plasticity, or pliability, is exhibited by gels. There is no standard test for determining the property of plasticity. Using water of plasticity (percent, of water, determined on an oven-dry basis at 105° C, necessary to develop the optimum plasticity of soil) to assess plasticity, differences in plasticity as a function of clay type can be seen in Table 5. Montmorillonite would be the most plastic; the minerals, kaolinite, illite, and halloysite exhibit less plasticity (chlorite would also be expected to exhibit similar behavior). Although no data are given, hydrous oxides and hydroxides would be expected to exhibit much lower plasticity and cohesion than the montmorillonite type of clay. Each clay mineral group can be expected to show a range of values because particle size, exchangeable cations, chemical composition, and crystallinity of the clay mineral exert an influence. In soils, the presence of non-clay materials, soluble salts, plus significant amounts of coarse particles and organic matter can temper the influence of the predominant clay species. In the case of montmorillonite, the water of plasticity value would be higher when the predominant species is sodium rather than calcium, magnesium, potassium, or hydrogen (the viscous condition increases as the value increases).

Table 5. Water of Plasticity
(in percent by weight)

Kaolinite	8.9 - 56.3
Illite	17 - 38.5
Halloysite	33 - 50
Attapulgite	93
Montmorillonite	83 - 250

(After White, 1947)

Shrinkage and Cohesion

These two properties are closely related to the property of plasticity.

When the water content of a clay gel is reduced, shrinkage occurs, and various structural units are developed. This shrinkage results in splitting of the soil mass into aggregates accompanied by a cohesion of the particles. Probably the tendency of the clay particles to stick together is due, in part, to the mutual attraction of the clay particles for water molecules held in between the particles. The clay mineral, montmorillonite, shrinks and cracks to a much greater degree than does kaolinite.

Swelling

The extent to which a clay mineral adsorbs water is determined primarily by the clay type. As can be seen in Table 6, the decreasing order of swelling is montmorillonite $>$ illite $>$ halloysite $>$ kaolinite (free swelling is defined as the increase in volume of the substrate upon the addition of a certain volume of water). For montmorillonite clays, the swelling decreases greatly with the exchange of sodium for other univalent ions or for divalent or trivalent ions. Baver and Winterkorn (1935) found that for Wyoming bentonite (montmorillonite type of clay), swelling decreased in the sequence, sodium $>$ lithium $>$ potassium $>$ calcium $>$ magnesium $>$ hydrogen.

Table 6. Free-swelling Data for Various Clay Minerals (in percent)

Ca-Montmorillonite	45 - 145*
Na-Montmorillonite	1,400 - 1,600
Na-Hectorite	1,600 - 2,000
Illite	15 - 60*
Kaolinite	5 - 60*

*Range of values due to variation in source area of clay mineral.

(After Mielenz and King, 1951)

The magnitude of swelling varies also with the variation in layer charge, particle-size distribution, electrolyte content of the aqueous phase, void size, and distribution.

The property of swelling directly affects the permeability of soils; the greater the degree of swelling, the lower the permeability of soils.

Flocculation

This term is applied to the coagulation of clay sols in the suspended state upon the addition of an electrolyte. Upon coalescence, these floccules settle to the bottom due to their combined weight. This same coalescing action apparently takes place in the soil, but much less rapidly, of course.

Although the coalescing capacities of various cations vary with the type of colloid, there are empirical rules to predict the behavior of the various cationic species; the most important is the Schulze-Hardy rule (van Olphen, 1963). It states that the coalescing power of indifferent electrolytes (i.e., electrolytes which do not react with the soil particle) is primarily determined by the valence of the ion, having a charge opposite to that of the particle charge: the higher the ion valence, the greater the flocculating power. Soils in the humid region are usually dominated with calcium, aluminum, and hydrogen (hydrogen acts as a divalent or trivalent ion, probably due to the presence of aluminum) and are generally coagulated. In contrast, high concentrations of adsorbed sodium causes a soil to become dispersed and sticky. Such conditions are found in certain sodic soils. The nature and concentration of the adsorbed cation thus can, for the same type of colloid present, influence the physical properties of the soil (e.g., permeability to water flow); a soil in a dispersed state is less permeable than one in the coagulated state.

In summary, the properties of soils as influenced by texture are shown in Figure 12. These are generalizations and indicate trends, some exceptions, e.g., the permeability to water of sandy soils having an indurated horizon, may arise.

BIOLOGICAL PROPERTIES

The soil is a living dynamic system. The microflora and fauna present in soil include actinomycetes, bacteria, algae, fungi, nematodes, protozoa, earthworms, and rodents. Biochemical degradation of these organisms and plant tissue annually supplies large quantities of organic residue to the soil. Since organic matter is derived from the metabolic products and tissue from various sources, the chemical composition of organic matter and humus (partially decomposed organic matter) is extremely complex; various components of organic matter have largely defied identification. However, since most organic matter originates with tissues of higher plants, it would be expected that such constituents as carbohydrates, fats, waxes, tannins, lignins, and proteins are present.

There are two significant multi-step biochemical cycles in the soil: the carbon cycle and the nitrogen cycle. In the carbon cycle, complex carbon-containing sources are degraded or completely oxidized to carbon dioxide by microorganisms; the organisms use carbon as an energy source.

In the nitrogen cycle, nitrogenous compounds are degraded or decomposed essentially in three steps:

(1) Aminization of proteins

(2) Ammonification

(3) Nitrification

The aminization reaction is:

$$\begin{array}{c}\text{Protein + Microbial enzymatic}\\ \text{action}\end{array} \longrightarrow \begin{array}{c}\text{Complex amino compounds + } CO_2 \text{ +}\\ \text{Energy + Other products}\end{array}$$

The amino compounds may be either incorporated into microbial cell tissue or changed to simpler products through the ammonification reaction.

Soil Property	Soil Texture		
	Sand	**Silt**	**Clay**
	Sand, Loamy Sand, Sandy Loam	Loam, Silt Loam, Silt, Sandy Clay Loam, Clay loam, Silty Clay loam	Sandy Clay, Silty Clay, Clay
Surface Area	———	———	——→
Molecular adsorption	———	———	——→
C. E. C.	———	———	——→
Swelling	———	———	——→
Plasticity	———	———	——→
Heat of wetting	———	———	——→
Water holding capacity*	———	———	——→
Infiltration*	←——	———	———
Percolation*	←——	———	———
Permeability*	←——	———	———
External drainage*	———	———	——→
Aeration*	←——	———	———
Organic matter content*	———	———	——→
Structure*	———	———	——→
Bulk density*	———	———	——→
Porosity (total)*	———	———	——→

*Colligative properties

Figure 12. The Effect of Soil Texture on the Physico-Chemical Properties of Soil

The enzymatic reaction called ammonification can be represented as:

$$\underset{\substack{\text{amino}\\\text{combination}}}{CR - NH_2} + HOH \xrightarrow[\text{hydrolysis}]{\text{enzymatic}} ROH + NH_3 + \text{Energy}$$

Of most interest, however, is the process of nitrification. Nitrogen in soils (added as a fertilizer amendment or present in soil organic matter) can be transformed to ammonia and then to the nitrate-nitrogen form. The retention power of soils for ammonium and nitrate forms of nitrogen differs markedly.

Nitrification is a two-step process and requires two different autotropic nitrobacteria. The transformation can be represented by the following two reactions:

$$2\ NH_3 + 3\ O_2 \xrightarrow[\substack{\text{nitrosococcus}\\\text{bacteria}}]{\text{nitrosomonas}} 2\ NO_2^- + 2\ H_2O + 4\ H^+ + \text{Energy}$$

$$2\ NO_2^- + O_2 \xrightarrow{\text{nitrobacter}} 2\ NO_3^- + \text{Energy}$$

The nitrate may disappear as a result of microbial reduction of nitrate through nitrite to N_2 and subsequent loss by volatilization.

Humus possesses more pronounced colloidal properties than do inorganic mineral fractions. Humus is adsorbed onto clay surfaces; the resulting clay-organic complex has colligative properties that differ in nature from either of the two constituents. As shown in Table 7, organic matter has a much higher cation exchange capacity than any clay mineral and has a surface area comparable to the expanding or swelling clay minerals.

With respect to physical properties, humus and organic matter (1) reduces plasticity and cohesion in soils, (2) increases water-holding capacity of the soil, and (3) encourages granulation in soils.

Table 7. Selected Physical Properties of Certain Soil Constituents

Soil Constituent	Physical Property Cation exchange capacity, Me. per 100 gram	Surface area, Sq. meters per gram
Organic matter	200 to 400	500 to 800
Vermiculite	100 to 150	600 to 800
Montmorillonite	80 to 150	600 to 800
Dioctahedral vermiculite	10 to 150	50 to 800
Illite	10 to 40	65 to 100
Chloriate	10 to 40	25 to 40
Kaolinite	3 to 15	7 to 30
Oxides and hydroxides	2 to 6	100 to 800

(After Bailey and White, 1964)

THE CHEMICAL CHARACTER OF SEWAGE

This section presents a synopsis of existing information on the quantitative and the qualitative chemical aspects of raw and treated sewage. This synopsis indicates what might be expected in treated sewage and, thus, what components in sewage effluent might react or interact with soil or soil constituents.

The chemical character of the treated waste effluent (with respect to both the nitrogenous and phosphatic constituents) would be expected to vary, depending on the contributing components in the raw sewage and the waste treatment method used.

Raw domestic sewage contains 15 to 35 parts per million (ppm) of nitrogen and 2 to 4 ppm of phosphorus (Sawyer, 1952). An average value for phosphorus, expressed as P_20_5, in raw sewage is 5.2 ppm; the range is 4.0 to 9.2 ppm P_20_5 (Rudolfs, 1947). However, this value may be much higher now due to increased use of detergents and water softeners; phosphorus is a major constituent of both substances. A value of 1.2 X 10^{-3} pound per capita per day has been estimated as the amount of phosphorus contributed by the use of synthetic detergents alone. Stumm and Morgan (1962) stated that the phosphorus content of domestic sewage was 3 to 4 times greater than that prior to the advent of synthetic detergents and that the phosphorus content of sewage may continue to rise. They also stated that aerobic biological treatment processes mineralize substantial fractions of bacteriological oxidizable substances, but are not capable of eliminating more than 20-50% of the nitrogenous and phosphatic compounds in sewage.

Cleason and Loonam (1933) analyzed sewage influent to a northside Chicago activated sludge plant and found that the total nitrogen level was 16.1 ppm (range 13-18 ppm); of this concentration, ammonia-nitrogen was 7.4 ppm and organic nitrogen, 8.7 ppm.

The sewage treatment method used determines the nitrogenous and phosphatic content of the treated waste effluent. Under plant-scale tests, using a treatment sequence (fine screening, high-rate trickling filter-secondary clarifier, low-rate trickling filter, and a final clarifier with 545 ppm of calcium oxide added to the final settling tank), the total nitrogen content of the sewage could be reduced from 7.4 to 1.7 ppm (77% reduction) (Owen, 1953). Under laboratory conditions (pH 10.9, settling time 1 hour, 540 ppm CaO), the total phosphorus content could be reduced from 6 to 0.3 ppm; 99% removal could be effected if settling time was increased from 1 to 18 hours (Owen, 1953). Rudolfs (1947) indicated that 50 to 60% of the total phosphorus could be removed with the use of settling alone, that filtration effected a 75 to 80% removal and that the activated sludge process reduced the initial concentration by 80 to 90%.

Similar results have been recorded by Hurwitz et al. (1965). The authors found that in a southwest Chicago treatment plant using the activated sludge process, the total PO_4 content was reduced by 77% (from 16.1 to 3.75 ppm). With regard to nitrogen removal, Cleason and Loonam (1933) found that in an activated sludge treatment plant on the north side of Chicago, the total nitrogen content was reduced by 73% (16.2 to 4.3 ppm); ammonia-nitrogen was reduced by 67% (7.4 to 2.5 ppm); and organic nitrogen was reduced by 79% (8.7 to 1.8 ppm).

From a comprehensive study of the Lake Tahoe watershed, McGauhey et al. (1963) suggested that the unit design factor for domestic water containing phosphate and total nitrogen should be 8 and 45 ppm, respectively, of the elemental form present.

It should be emphasized that results expressed as percentages, although impressive, may be misleading. It is necessary to know two quantities before percentage reduction can be properly interpreted: (1) the initial concentrations in the influent and (2) these values must be compared to tolerence levels for nitrogen and phosphorus, principally that level which promotes algae growth and water quality problems.

Analytical data from seventeen Wisconsin lakes led Sawyer (1952) to conclude that waterborne concentrations of soluble phosphorus in excess of 0.01 ppm and inorganic nitrogen in excess of 0.30 ppm at the spring turnover time would produce algal blooms, constituting a nuisance. Similar conclusions were reached by Sylvester (1961): a nitrate-nitrogen concentration greater than 0.2 ppm and a soluble phosphorus concentration greater than 0.01 ppm would support algal blooms and constitute a nuisance.

Sawyer and Ferullo (1961), based on a laboratory study of nitrogen fixation in natural waters, believed that: (1) sewage plant effluents contained excessive amounts of phosphorus; (2) fertilization of aquatic regions by domestic wastes stimulated biological productivity; an (3) excessive amounts of phosphorus could stimulate extensive blooms of nitrogen-fixing blue-green algae.

Based on foregoing information, it appears that nitrogen and phosphorus concentrations in treated sewage effluent exceed those levels where stimulation of algal growth occurs and thus, the "nuisance potential" is exceeded, even when the most efficient conventional treatment systems are used.

Various methods have been used to lower the soluble phosphate content in sewage treatment plant effluents; however, the data usually do not show whether the insoluble phosphates were removed. Rohlich (1961) reported that laboratory studies at the University of Wisconsin and at the Madison treatment plant indicated that 96 to 99% of soluble phosphorus could be removed by physical-chemical precipitation using additives (alum, ferrous sulphate, ferric sulphate, or copper sulphate); alum appeared to be the most suitable coagulant. The "Pitcon process" removed approximately 95% of both total and soluble phosphate, but had little effect on total nitrogen; the major effect on nitrogen was the conversion of organic nitrogen to ammonia. Neither process was evaluated as to its economic merit. The use of ion exchangers (Nesselson, 1958) or air stripping of ammonia (Kuhn, 1954) for nitrogen removal was found to be economically prohibitive.

It appears that, at the present time, there is no single method that is both functional and economically feasible for use in removing sufficient amounts of nitrogen and phosphorus from sewage treatment-plant effluent, before disposal into a watercourse or into the hydrologic cycle.

With this in mind, the following section reviews the literature on the principles of soil science and nitrogenous reactions, with respect to the use of soil as a waste treatment method and a means for waste disposal.

BEHAVIOR OF NITROGEN IN SOILS

The leaching of nitrogen, phosphorus, and other nutrients in soils has been investigated mainly by collecting and analyzing water from either tile drains or lysimeters. In the first method, an area is selected in which the tile drain receives only the water from the land under study. The flow is recorded periodically, and analyses of the drainage water indicate nutrient and water losses. The advantage of this method is that a large area of soil may be studied under normal field conditions.

However, the usual method has been the use of a lysimeter (see glossary and Kohnke et al. (1940). In lysimetry, the leachate from either a disturbed or undisturbed soil column is collected, the amount of water is determined, and the leachate is chemically analyzed for the elements of concern. The advantages of using a lysimeter over a tile-drainage system are: (1) variations in a large field are avoided and (2) the study is more easily controlled and less expensive.

Kohnke et al. (1940) stated in their summary that soil texture, soil structure and exchangeable cations influence the rate of percolation which, in turn, influences the magnitude of the leaching losses. Percolation is more rapid (and of greater volume) through coarse-textured soils than fine-textured ones. Percolation is more rapid when the soil has a porous crumb structure and when the cation complex is staurated mainly with calcium and aluminum rather than sodium (due to the dispersive action of sodium).

MOVEMENT OF NITROGENOUS COMPOUNDS IN SOILS

Inorganic Nitrogen Compounds

Most soil research on nitrogen has been on the leaching losses of nitrate-nitrogen (NO_3^--N), ammonium-nitrogen (NH_4^+-N), and nitrite-nitrogen (NO_2^--N) from soils. However, some work has been done on the reactions of other nitrogenous forms with soils; these are discussed in the next section.

The ammonium and nitrite forms of nitrogen constitute only a small portion of the total nitrogen removed. Results of lysimeter studies in California and New York showed that nitrate is the predominant form of nitrogen in percolating water--more than 99% of the soluble nitrogen was in the nitrate form; although, under certain circumstances, appreciable amounts of ammonia and organic nitrogen including urea can be found in the leachate (Chapman et al., 1949; Collison and Mensching, 1930). Less than 1% was present as ammonia; and only a trace was present as nitrite (Collison and Mensching, 1930). The explanation for the low nitrite level was that only a small concentration was present in the soil, while the low loss of ammonium was attributed to the fixation by the colloidal exchange complex.

Usually all the nitrogen in leaching waters is in the nitrate form and the ammonium form is either held by the exchange complex or oxidized to nitrates by microbal action and thus, is lost (Kohnke et al., 1940). In peat soils, a large amount of ammonium-nitrogen was found in the leachate; this was attributed to the reducing power of the peat (Benson and Barnette, 1939; Joffe, 1940; Bates and Tisdale, 1957; and Il'in, 1959). More recent work (Smith, 1944; Broadbent and Chapman, 1950; and Shopkhoev, 1958) confirms earlier findings that applied nitrogen present in the nitrate form (or converted to nitrate by microbial action) is easily and generally completely removed from the soil profile by percolating waters.

Calvert (1962) found that heavy application of water to the soil surface caused solution of applied nitrate fertilizers and redeposition at depths of 30 inches or more. Simakin and Vasilenko (1965), found that nitrate, naturally in the soil (leached chernozem) or applied as fertilizer (NH_4NO_3), was almost completely leached from the top 15 centimeters into the subsoil during the winter and early spring, and was subsequently carried into ground water wells, and into the Kuban River.

The nitrogen form present or applied to soil greatly affects the leachability of the material. Benson and Barnette (1939) studied the leaching characteristics of four sandy soils, applying various forms of nitrogenous fertilizer. They found that all nitrogen applied as nitrate (NO_3) was leached out of the profile. One-third of the amount applied as $(NH_4)_2SO_4$ and NH_4NO_3 was leached. Very little $(NH_4)_3PO_4$ was removed. Also, the four soils retained $(NH_4)_2CO_3$ very efficiently until nitrification began. Urea was not leached at all when immediately assayed, but after 1- and 4-day incubation periods, 35 and 60%, respectively, were lost. Bates and Tisdale (1957), by a multiple regression analysis of data from column leaching-studies of eight coarse-textured North Carolina Coastal Plain soils, found a relationship between nitrate movement, amount of percolating water, and soil porosity. The relationship was:

$$Y = 1121.93 + 64.66X_1 + 5.83X_3$$

Where

Y = mean movement of nitrate in centimeters
X_1 = porosity index of soil
X_3 = porosity index times amount of water added

The regression accounted for 87.6% of the treatment sum of squares and was highly significant. Other factors found to influence nitrate movement included: (1) the degree of soil aggregation (soil structure-related factor); (2) the nature of the accompanying ion; and (3) the form in which the nitrate was present.

Loss of nitrate by leaching is proportional to the nitrate concentration and loss of water. Leaching of nitrate-nitrogen may be very intense in irrigated agriculture where most of the applied nitrate enters the ground water.

In field work on four drainage systems and two soil types in the San Joaquin Valley of California, Johnson et al. (1965) recorded the applications of fertilizer and irrigation water and determined the amount of tile effluent drainage from a number of plots. They analyzed the drainage water for total nitrogen and phosphorus as well as for nitrate-nitrogen and ammonium-nitrogen. Most of the nitrogen in the effluent was in the nitrate form. However, up to 7.1 ppm of nitrogen (in the form of ammonium) were lost immediately after application of nitrate; also, nitrogen as organic nitrogen and nitrite in concentrations up to 1.3 and 0.01 ppm, respectively, were lost. On a weighted average basis (average weighted on the basis of discharge), the concentration of nitrate was 21.1 ppm; the range was 1.8 to 62.4 ppm. The authors indicated that the chemical composition of the drainage effluent would be influenced by: (1) hydraulic conductivity of soil; (2) salinity; (3) cation exchange capacity of soil; (4) stratification; and (5) physical arrangement of the drainage system.

Organic Nitrogen Compounds

Movement or leachability of an organic compound is a function of two parameters: (1) ease of adsorption/resistance to desorption and (2) water solubility.

As indicated by Bailey and White (1964), the amount of adsorption is determined by the interaction of such micro-factors as: (1) nature of adsorbent; (2) nature of adsorbate; (3) soil reaction; (4) nature of cationic species on soil exchange complex; (5) soil moisture content; and (6) temperature of soil.

The second parameter, water solubility of a compound, is influenced by the rate at which water passes through the soil and by the concentration of the solute in question.

Organic nitrogen containing herbicides of interest include s-triazines, substituted ureas, carbamates, acetamides, anilides, and amides. Over a wide range of soil and environmental conditions, the two most common s-triazines, simazine and atrazine, as well as the substituted ureas, fenuron, monuron, diuron, and neburon, are not very mobile in soils; they are generally not leached past a 4-6 inch depth (Hill et al., 1955; Abel, 1957; Upchurch and Pierce, 1957 and 1958; Sheets, 1958; Montgomery et al., 1958 and 1959; Subra and Guillemot, 1959; Stroube and Bondarenko, 1960; Ashton, 1961; Dewey, 1961; Burnside et al., 1961 and 1963; Rodgers, 1962; Stroube, 1962; Geissbühler et al., 1963; and Wiese and Davis, 1964). However, the behavior of such organics is difficult to predict in continuously water-laden soils.

Herbicides such as dipropalin (N,N-dipropyl-2, 6-dinitro-p-toluidine), diphenamid (N,N-dimethyl-2, 2-diphenylacetamide) and diphenatrile (diphenylacetonitrile) exhibit a slightly greater mobility (Pieczarka, 1961), while CDAA (2-chloro-N,N-diallylacetamide) did not leach past 3 inches with 2 inches of rainfall (Helgeson and Anderson, 1955). However, more rainfall would probably leach CDAA to greater depths.

REACTIONS OF VARIOUS FORMS OF NITROGEN IN SOILS

Reactions of various nitrogenous forms with soils bears directly on the problem of retention or movement through soils and determines whether nitrogenous sewage components are held in the soil.

Ammonia

One form of nitrogen which might be present in sewage waste effluents is the molecule ammonia. Obviously, reactions of ammonia (NH_3) cannot be divorced from the reactions of the ammonium ion (NH_4^+) in soils. For clarity, a distinction should be made between these different forms of nitrogen. Ammonia is an electrically neutral, but highly polar molecule. The ammonium ion possesses an electrostatic charge and therefore exhibits properties similar to those of other cations in solution. The ammonia molecule is pyramidal in configuration.

In the literature, the terms "ammonia" and "ammonium" have been used interchangeably. Under alkaline conditions, the concentration of ammonia may be relatively high in comparison with that of the ammonium ion. A one-molar solution of ammonia in water at 25° C is only 0.00426 M with respect to the ammonium ion.

From the standpoint of physical chemistry, the ammonia molecule can be adsorbed chemically and/or physically (Bailey and White, 1964). Chemical adsorption would be expected where hydrogen is present as an ion or as a constituent of hydrated aluminum ions. In the case of reaction with hydrogen ions associated with a clay mineral or organic matter, the ammonium ion would be formed since ammonia is a very strong base and would accept the proton and form NH_4^+, the conjugate acid. If this occurs, the ammonium ion becomes the exchangeable ion on the mineral's exchange complex.

Physical adsorption would be expected to occur by a hydrogen bond between a hydrogen atom of the ammonia molecule and an oxygen on the clay surface (NH.....0). Since ammonia can form "hydrates" with various salts, such as $CaCl_2 \cdot 2NH_3$, similar to genuine hydrates, the ammonia molecule may form such hydrates with exchangeable bases on the cation exchange complex of the soil systems.

Both chemical and physical adsorption of ammonia by such soil constituents as clay minerals and organic matter has been observed experimentally. Buswell and Dudenbostel (1941) observed that ammonia was chemically adsorbed by a hydrogen-saturated clay; the ammonia reacted with hydrogen-saturated layer-lattice silicates to form an ammonium-saturated clay. Jenny et al. (1945) and Mortland (1955) both showed that ammonia could be physically adsorbed by clays and clay minerals. This type of adsorption was established by showing (1) the easy reversibility of adsorption and (2) the low energy of adsorption. Working with a soil clay (Yolo clay) which had been hydrogen-saturated (actually an H-Al clay system), Jenny et al. (1945) demonstrated that ammonia adsorption occurred simultaneously by both chemical and physical adsorption. The nature of the substrate affected the magnitude of ammonia adsorption. Mortland (1955), using a vapor-phase adsorption technique and the Brunauer, Emmett, Teller equation, found that ammonia adsorption by three soil components decreased in the following order: muck, bentonite, and kaolinite (cation exchange capacity also decreased in this order). The heat of adsorption of ammonia by bentonite was determined by using a thermodynamic relationship (Classius-Clapyron equation) and sorption isotherms. The surface sites of adsorption on bentonite were markedly heterogeneous since the heats of adsorption varied according to the amount of surface covered.

By combining X-ray diffraction, infrared spectroscopy, calorimetry, and ND_3 and D_20 isotopic exchange techniques, Mortland et al. (1963) demonstrated that: (1) chemisorbed NH_3 was present as NH_4^+ ions rather than as the molecular form and (2) ammonia (as NH_4^+) was chemisorbed by base-saturated clay mineral samples; the reaction was between the NH_3 and residual water on the interlamellar surfaces. These authors speculated that certain observed spectral features of NH_3 could be attributed to the amination reaction ("hydrate" formation) or to physically-adsorbed species.

Much of the ammonia sorbed by various kinds of organic matter is in a non-exchangeable form and is resistant to decomposition. Broadbent et al. (1960) found that an ammonia-organic matter combination was so stable chemically that it was not broken down by refluxing with 6 N HCl for 16 hours. Ammonia fixation was found to be a linear function over the range from pH 4-9. Thus it would be necessary to use basic waste effluents to maximize adsorption by soil organic matter.

Several factors can affect the loss of adsorbed ammonia from soil. Volatilization occurs when the ammonia concentration is high and the ability of the soil to react with the ammonia is low. The volatilization would be high especially from mucky, humic, and peat soils because ammonia is produced from organic matter. Because water retains ammonia, a low moisture content reduces the amount of ammonia dissolved in the water and promotes volatilization.

Of greater importance than the water content, however, are the cation exchange capacity and pH of the soil. These properties affect the ability of the soil to react chemically with ammonia.

Under the pH conditions normally found in soils (pH 4 - 9), ammonia probably is chemically adsorbed by clays in an exchangeable form and by the organic matter in the alkaline range. Using manometric techniques, Brown and Bartholomew (1963) studied the effects of the interactions of moisture content, ammonia concentration, and cationic species on the adsorption of ammonia by bentonite and halloysite. The adsorption isotherms indicated that, when the ammonia vapor pressure was less than 60 mm. Hg, dry clays adsorbed more ammonia than comparable moist clays. At a vapor pressure in excess of 60 mm. Hg, the greater the water content the greater the amount of ammonia adsorbed. The decreasing order of cationic influence on magnitude of adsorption was aluminum to calcium to potassium. Evidence was also presented that site competition occurred.

In an earlier study using a similar technique, Brown and Bartholomew (1962) found that at a pH of 7, synthetic gibbsite did not chemically adsorb ammonia. They reasoned that, since $Al(OH)_3$ is basic in nature, a hydroxyl group and not a hydrogen group, would be expected to be dissociated. Also, potassium- and ammonium-saturated systems adsorbed less ammonia than did bentonite saturated with such ions as hydrogen, aluminum, calcium, or magnesium. Apparently, certain ions decrease or prevent the adsorption of ammonia, a property of importance in a soil column waste-effluent system.

Ammonium

Previously, it was noted that ammonia may react with acid soil systems and become chemically adsorbed by either an amination reaction (hydrate formation) or proton association. Because ammonium is near the bottom of the lyotropic series, it is very easily replaced. Hence, the ammonium ion in a readily exchangeable form, would be readily leached from a soil upon exchange with other ions in the percolating soil (or waste) solution. Some, however, are not readily exchanged and are "fixed." The phenomenon of ammonium fixation has been reviewed by Gieseking (1949), Reitemeier (1951) and Grim (1953).

Ammonium fixation commonly occurs in soils and has even occurred in rocks (Stevenson, 1959). Conditions such as drainage, vegetative cover, and the extent of leaching have little effect on the fixed ammonium content of soils (Stevenson and Dhariwal, 1959).

The following 15 factors affect and determine ammonium fixation and release:

(1) Amount of clay-size particles (Stevenson, 1959). In general, the more clay present, the greater the fixation of ammonium.

(2) Types of clay minerals present. The mica-type clay minerals (vermiculite, mica-vermiculite, illite, and montmorillonite) are responsible for ammonium fixation; also for potassium fixation--the same mechanism is generally believed to apply to both potassium and ammonium. (Volk, 1934; Stanford and Pierre, 1947; Joffe and Levine, 1947; Bower, 1950; Barshad, 1950; Allison, Kefauver, and Roller, 1953; and Doetsch, Roller, and Allison, 1953).

(3) Magnitude of layer lattice charge of clay minerals (Barshad, 1954a). The higher the layer charge, the greater the percentage of ammonium ion fixed.

(4) Particle size (Barshad, 1954b). Ammonium fixation decreases as particle size increases.

(5) Presence of exchangeable hydrogen on the exchange complex, (Barshad, 1954a). Ammonium fixation is inversely related to the content of exchangeable hydrogen.

(6) Nature of the replacing cation (Barshad, 1954a). The ease of replacement of the fixed ammonium is barium > lithium > sodium > magnesium > calcium.

(7) Nature of interlayer potassium present (Barshad, 1954a). Ammonium fixation is greater if interlayer potassium is fixed rather than native in origin.

(8) Origin of layer-lattice charge. Minerals having an unbalanced charge predominantly in the tetrahedral layer possibly fix ammonium more effectively than minerals with an unbalanced charge predominantly in the octahedral layer (Wear and White, 1951). On the other hand, the magnitude of the layer charge--not the site of origin--may be the governing factor in both ammonium and potassium fixation. (Barshad, 1954b).

(9) Competition for adsorption site. Potassium, either in the crystal lattice or in the reacting solution, blocks the fixation of ammonium. Minute amounts of potassium or ammonium in the solution prevent the release of fixed ammonium from soils. (Stanford and Pierre, 1945; Barshad, 1954a; Hanway and Scott, 1956; Scott, Hanway, and Edwards, 1958; Edwards, 1961; and Leggett and Moodie, 1963).

(10) Moisture status. Bentonite fixes ammonium on drying, but not while moist (Page and Baver, 1940; Joffe and Levine, 1947; Allison, Kefauver, and Roller, 1953; and Allison, Roller, and Doetsch, 1953). Walsh and Murdock (1960) found twice as much fixation after soil was frozen as when it was moist and un-frozen.

(11) pH of the soil system. Scott, Hanway, and Edwards (1958) found that more ammonium could be removed from vermiculite with a sodium-extracting solution with decreasing pH. A linear relationship was found.

(12) Surface vs. subsurface soils. Greater fixation occurs in the subsoil than in surface horizons (Allison, Roller, and Doetsch, 1953; Rich, 1960; and Walsh and Murdock, 1960). Allison, Roller, and Doetsch (1953) found that the subsoil fixed 5 to 10 times more ammonium than the surface soils.

(13) Presence and extent of development of aluminum interlayers. Rich (1960) found that ammonium fixation decreased with increasing development of aluminum interlayers. Aluminum interlayers decreased the cation exchange capacity of minerals and thus decreased the sites available for ammonium fixation. Also, they prevent closure of the lattice layers of vermiculite and hence, prevent entrapment of ammonium.

(14) Strength of ammonium fixation as a function of the nature of the clay mineral. The order of the strength of fixation was found to be vermiculite > illite > montmorillonitic soil (Allison, Kefauver, and Roller, 1953).

(15) Nitrification. Fixation of ammonium greatly reduces nitrification of ammonium by bacteria (Allison, Kefauver, and Roller, 1953 and Allison, Roller, and Doetsch, 1953). Such a reduction is of great importance since the product of nitrification is nitrate, which is highly leachable.

The mechanism by which ammonium (also potassium) is fixed while other cations (e.g., lithium, sodium, calcium, and magnesium) are not, is based on: (1) ionic size of the dehydrated ions; (2) the expandability and contractibility of the mica-like or 2:1 type clay minerals; and (3) geometric arrangement of the oxygen ions at the silicate surface. The major tenets of the theory of Page and Baver (1940) are as follows:

(1) Exposed interlamellar surfaces of micaceous minerals consist of sheets of hexagonally-arranged oxygen ions. Radoslovich (1960, 1961, 1962a, 1962b) proved that the opening is not hexagonal but actually is ditrigonal, the opening within the "hexagon" being 2.8 angstroms in diameter.

(2) Dehydration of clay prompts contraction of the layers; ions lose water of hydration and approach the unhydrated ionic diameter (ammonium ion diameter, 2.96 Å; potassium ion diameter, 2.66 Å).

(3) Ions having a diameter close to those of the "hexagonal" openings fit into the openings in adjacent silicate layers. Further contraction locks-in the ions against further rehydration. Larger ions do not fit into the openings; hence, these cations are loosely held between the layers and are accessible for rehydration. Small cations enter the openings but make insufficient contact with adjacent layers to effect strong binding. Therefore, ammonium is fixed or retained by the 2:1 type clay mineral such that it does not leach through the soil and enter the sub-surface or ground water. Ammonium is held in such a tenacious manner by the 2:1 type clay mineral that it is very difficult for the ion to be desorbed and moved out of the profile.

Urea

Little is known about the retention of urea in soils. Chemically, urea (NH_2CONH_2) is a weak base; $K = 1.5 \times 10^{-4}$.

Chin and Kroontje (1962) found that a urea solution (50-1,000 ppm), adsorbed by soil, obeyed the Freundlich adsorption isotherm (adsorption magnitude related to amount of solute in equilibrium with the adsorbent). The adsorption of urea by soils or soil cellulose mixture (representative of organic matter) was 2 to 3 times greater during dry than wet conditions and varied between soils. All the urea was desorbed by 50 ml of water from Yolo loam (a high montmorillonite-content soil), Norfolk fine silt loam, and Norfolk sand; while, Salina clay and Tatum silt loam (mainly dioctahedral vermiculite and kaolinite) required 2,500 and 1,000 ml of water, respectively, to desorb equivalent amounts. The difference in desorption ease was attributed to a difference in adsorption mechanisms. Physical adsorption was the postulated mechanism for the first three soils and chemical adsorption for the last two. Adsorption of urea by organic matter was attributed to both physical adsorption and complex formation. The cation exchange capacity, pH, and clay content, were not found to be significant in urea sorption. The authors concluded that soils in general have a weak affinity for urea.

In contrast, Hourigan and Seay (1957) reported that in Kentucky soils urea was fixed by soil colloids and that leaching of urea was not observed under field conditions.

Mitsui and Takotoh (1963) used infrared spectroscopy to study the interactions between urea and soil constituents. The authors used a wide range of adsorbents including five paddy soils, kaolinite, bentonite, and allophane; both anionic and cationic exchange resins, and humic acid. The N-H stretching band at 3500 cm^{-1} shifted to 3400 cm^{-1}. Urea adsorption was attributed to hydrogen bonding to such functional groups as Si-OH (of amorphous clays); the

OH at the broken edge of the clay; and COOH, OH, and C = 0 (functional groups in organic matter). However, a later infrared study by Mortland (1966) clearly indicates that urea is principally adsorbed not by hydrogen bonding of the NH group to the clay surface but either by protonation of the carbonyl group (C = 0) or by interaction of the carbonyl group with the exchangeable cation (i.e., an ion-dipole type electrostatic bond).

Urea is hydrolyzed to ammonia in soils by the enzyme, urease (Conrad, 1940a, 1940b; Simpson and Melsted, 1963). Rate of hydrolysis varies between soils (Benson and Barnette, 1939; Simpson and Melsted, 1963) and is a temperature-dependent reaction.

BEHAVIOR OF PHOSPHORUS IN SOILS

The average total phosphorus concentration in soils varies from 0.007 to 0.11%; but, generally it is less than 0.05% except in young soils (Dahnke et al., 1964). Expressed in another manner, soils usually contain 0.10 to 0.25% P_2O_5 and hardly ever more than 0.5%.

For purposes of waste disposal, information on the actual quantity of phosphorus that soils are capable of fixing is of paramount importance. The very large phosphorus fixation capacities of some soils can be seen in Table 8. For example, to satisfy the phosphorus-fixing power of the unlimed Collington soils, nearly 47 tons of superphosphate containing 20% P_2O_5 would be required. One Coastal Plain soil was reported to have a phosphate-fixing capacity of 125 tons of 20% superphosphate per acre-furrow-slice (Bear and Toth, 1942).

For agricultural purposes, land having a high phosphorus-fixation power poses a great problem. However, for use as a waste effluent soil treatment system, the greater the fixation capacity the more efficient and the longer lasting the "column" would be. It also should be remembered that the amount stated above applied only to the top 6 inches (acre-furrow-slice). The lower soil horizons also have a large fixation capacity; but, as will be pointed out, the greatest phosphorus fixation capacity appears to be in the A horizon.

Movement of Phosphorus Compounds in Soils

In contrast to the high mobility of nitrate-nitrogen in soils, most phosphorus-bearing compounds react vigorously with the soil and very little passes through the soil profile into the ground water.

Table 8. The Phosphorus Absorbing Power of Three New Jersey Soils. Limed and Unlimed Expressed as Pounds of 20 Percent Super Phosphate per Acre Furrow Slice (A.F.S.)

Soil	Treatment	pH	P-Fixing Power, Lbs. 20% Super Phosphate Per A.F.S.
Sassafras	No lime	3.6	28,400
Sassafras	lime	6.5	13,916
Collington	No lime	3.2	93,720
Collington	lime	6.5	50,268
Dutchess	No lime	3.8	68,728
Dutchess	lime	6.5	44,020

(After Toth and Bear, 1947)

Results of a two-year study of the nitrogen and phosphorus content of tile drainage from two soils in the San Joaquin Valley, California, following fertilizer application and intensive agriculture, indicated that the percentage of applied phosphorus lost varied from 1 to 17%; but the concentration ranged from 0.053 to 0.23 ppm (on a weighted average in accordance with discharge (Johnson et al., 1965). The authors stated that concentrations of 0.079 ppm phosphorus and 25.1 ppm nitrogen (on a weighted average in accordance with discharge) would promote the growth of algae, as evidenced by growth in the drainage ditches downstream from each tile drainage system.

The lysimetry work of Morgan and Jacobson (1942) provided further evidence that phosphorus was essentially not leached from soils. In this study, fertilizer was added to a soil in an amount equivalent to 3,005 pounds of phosphorus per acre over an 11-year period. The average leaching loss through an 18-inch soil depth was 0.1 pound of phosphorus per acre per year. In sixteen other sets of lysimeters receiving phosphorus in amounts ranging from 481 to 973 pounds per acre during an 11-year period, only one set lost a measurable amount of phosphorus. Similarly, only a trace of phosphorus was lost during lysimetry studies on Dunkirk silty clay loam and the Volusia silt loam for a 10-year period (Bizzell and Lyon, 1927). Kohnke et al. (1940), in their summary of lysimeter work of 250 years, indicated that only trace amounts of phosphorus had ever been found in the percolate. Furthermore, the authors stated that only in light-textured soils which have been heavily fertilized would a small amount of phosphorus percolate through the profile.

It should be pointed out that, especially in the case of phosphorus, the analytical methods presently used to determine the concentration of phosphorus are more sensitive than those used in the first part of this century. But, for present purposes, relative amounts are sufficient to demonstrate the general principles of phosphorus retention by soils.

Factors Affecting Phosphorus Fixation by Soils

Several factors play a distinct and important role in phosphorus fixation: type of soil, particle size, pH, reduction potential, temperature, organic content, and reaction time. Each factor will be discussed separately.

Soil-Type Effects

Since soils are formed by different combinations of soil-forming factors and thus, differ in physico-chemical properties, it would be expected that soils would differ in their ability to fix phosphorus. Also, as expected, the total amount of phosphorus present as well as the total organic and inorganic phosphorus contents differ among soils. Williams (1959) in a study of the influences of parent material and drainage on soil-phosphorus relationships, found that soils formed from basic igneous rocks had a higher content of total and inorganic phosphorus than soils formed on slate, granite, and sandstone. In addition, phosphate adsorption capacity was greatest in soils formed from basic igneous rocks. In the same study it was found that, irrespective of the parent material, the following were associated with poorly-drained soils, in comparison to well-drained soils:

(1) Lower total phosphorus level;
(2) Much lower total organic phosphorus level;
(3) Lower ratio of organic to total phosphorus;
(4) Higher acid-soluble phosphorus content and higher percentage of inorganic phosphorus extractable by acid;
(5) Lower ammonium flouride-soluble inorganic phosphorus content;
(6) Lower acid-oxalate-soluble aluminum, but similar or higher acid-oxalate-soluble-iron content; and
(7) A much lower ammonium-soluble aluminum content.

Soil profiles differ in adsorption characteristics. The great soil groups, Podzol, Serozem, Chernozem, and Yellow earth adsorbed phosphorus uniformly throughout the profile. While, in the case of Krasnozem soils, phosphorus was adsorbed in the upper layers only (Rachinskii, 1954). Phosphorus (present in the water soluble form) could be eluted from the four great soil groups mentioned; but not from the Krasnozem soil; a 1N sodium hydroxide solution was necessary to elute the phosphorus from this soil. Brown (1952) found that soils formed from basaltic parent material exhibited a much higher phosphorus fixation capacity than Silurian-derived soils.

The phosphorus fixation capacity (the extracted electrodialyzed clay fractions) from A_1, A_2, and B horizons of two Coastal Plain soils (Bladen and Norfolk series) was determined by Hester (1937). Results from the study showed that, as compared to the initial phosphorus content, the A horizon had an eightfold increase after reaction with solutions containing varying concentrations of phosphorus; the A_2 horizon had an approximate fivefold increase; while the phosphorus content of the B horizon did not change appreciably. Such a study indicates that most of the applied phosphorus (from solutions such as waste effluents) is fixed in the A or the surface horizon.

In a study of Rumanian soils, Serbanescu and Blaunaru (1963) found that degraded podzols and podzolized brown soils were low in mobile aluminum phosphate, while leached Chernozem soils contained the various forms of phosphorus in well-balanced proportions. In the Steppe Chernozems, phosphorus occurred mainly as calcium-aluminum-phosphates.

Particle Size Effects

The effects of particle size on phosphorus adsorption depend on: (1) the soil separate in which maximum phosphorus fixation occurs and (2) the fraction in which most of the inorganic or organic phosphorus occurs.

The importance of the above can be seen in the works of Kanwar (1956). A lateritic-podzol soil with gravelly sandy-loam texture, containing 10% clay, had a phosphorus retention capacity of 1,500 ppm PO_4; of this, only 2% of the total adsorption was attributable to the clay particle-size fraction. In the case of a red-brown earth of loamy texture having a 62% clay content, 80% of the phosphorus adsorbed was retained by the clay fraction. This suggests that adsorption may not strictly depend on the amount of clay, but on the physico-chemical nature of the constituents comprising the clay fraction.

In soils derived from basic igneous rocks, slates, sandstones, and granites, most of the organic phosphorus was in the clay fraction; while 20-60% of the inorganic phosphorus in the topsoils occurred in the sand fraction (Williams, 1959).

pH Effect

The pH of the soil system is a dominating factor in phosphorus fixation. The products of phosphorus, produced by reactions with the soil, are determined by the soil pH or soil reaction. In an acid environment (considering solubility products), a predominance of aluminum and iron phosphates would be expected; while in an alkaline environment, calcium phosphates would be expected to predominate. A minimum of phosphorus fixation occurs when the soil is "neutral", pH 6 to 7. Phosphorus fixation as a function of pH is shown in Figure 13.

Most of the discussion on the role of pH on phosphorus fixation will be deferred to the section on "reaction mechanisms." The soil reaction influences: (1) the amounts of iron, aluminum, and manganese in the soil solution; (2) the nature of iron-, aluminum-, and manganese-containing minerals; (3) the available calcium present; and (4) the amount and extent of organic decomposition.

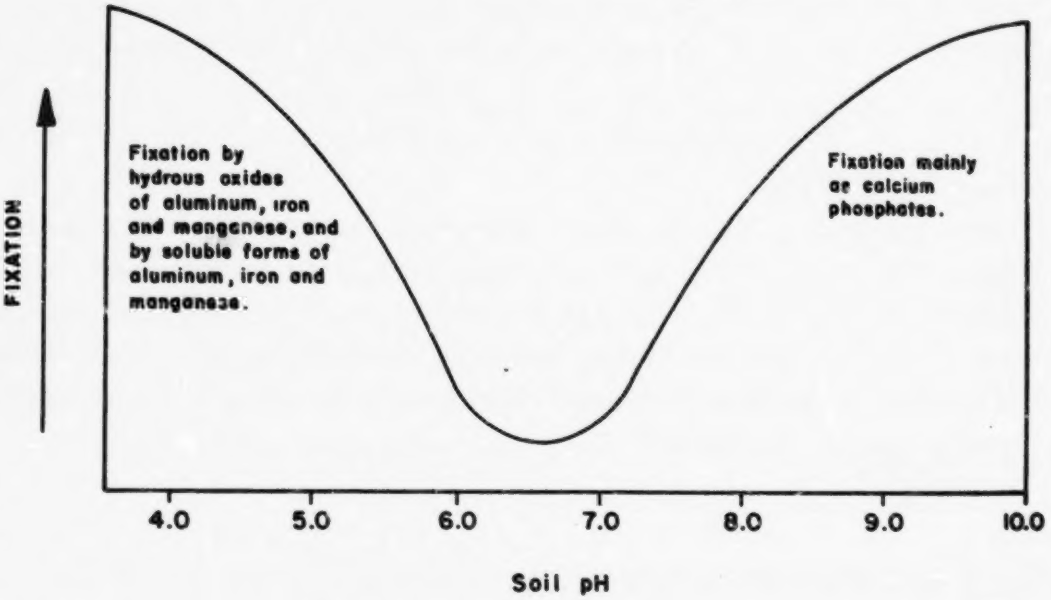


Figure 13. Form of Phosphorus Fixation as a Function of Soil pH. Above Illustrates Average Conditions and no Inference Should be Made to any Particular Soil

Effect of Reducing Conditions

Water-saturated soils in the presence of decomposing organic matter cause reducing (anaerobic) conditions. Oxidizing or reducing conditions can be determined by eH measurements (the determination of the redox-potential).

Reducing conditions in soils increase phosphorus fixation especially in soils high in phosphorus (Popvic, 1958). This has been attributed to the greater solubility of iron ($Fe^{+3} + e^{-} \rightarrow Fe^{+2}$) after reduction occurs and the pH is lowered. Mack (1959) found that partially anaerobic conditions increased the proportion of acid-soluble phosphorus fraction, while aerobic conditions (oxidizing conditions) decreased the acid-soluble aluminum-phosphate fraction and increased the alkali-soluble phosphorus fraction.

Effect of Temperature

Mack (1959) found that an increase in temperature increased the amount of water-soluble phosphorus that could be leached from a soil system. He noted also that a greater amount of phosphorus could be leached from a soil that had been frozen than one that had not been frozen.

Effect of Organic Matter

From a scant amount of research, it appears that organic matter and derivatives of organic matter may retard or enhance phosphate fixation. A study of the retention of phosphate ions by $Fe(OH)_3$, $CaCO_3$, and clays from solutions containing H_3PO_4, ammonium nitrohumate, ammonium humate and sodium humate indicated that, in general, humates retarded phosphate fixation (Hashimoto and Okuda, 1962). However, in certain cases (e.g., $Fe(OH)_3$), phosphorus fixation was enhanced.

Effect of Phosphorus Concentration and Time of Reaction on Fixation

Sen Gupta and Cornfield (1963) found that in soils, having either a high (16.5%) or low (0.15%) calcium carbonate percentage, the phosphorus fixation of added phosphorus increased as the reaction progressed; usually the fixation decreased when increasing amounts were applied. A somewhat different observation was made by Benku et al. (1963) on the adsorption of P^{32}- labeled KH_2PO_4 by a gray-brown podzolic soil. Phosphorus fixation increased as the time and concentration of the reaction solution increased.

Reactions of Phosphorus Compounds in Soils

Inorganic Phosphorus Fixation Mechanisms

This discussion has shown that phosphorus becomes fixed in soils, but the mechanisms of phosphorus fixation have been mentioned only briefly. Fixation is the process whereby readily soluble compounds are changed into less soluble forms by reaction with inorganic or organic components of the soil with the result that the compounds become restricted in their mobility in the soil (Hemwall, 1957a).

Inorganic phosphorus in soils exists almost entirely as salts of orthophosphoric acid. These salts can be classified generally as oxy-, fluoro- and hydroxy-phosphates of iron, aluminum, calcium, titanium, magnesium, and manganese.

In all fixation reactions in which phosphorus is involved, one or more of the ionic forms of orthophosphoric acid may be present. Buehrer (1932), using ionization constants for H_3PO_4, calculated the relation of pH to the relative concentration of the undissociated H_3PO_4 and the three ionic species, $H_2PO_4^-$, HPO_4^{-2}, and PO_4^{-3}. Over the pH range of 4.0 to 8.0 (this range encompasses the majority of most agricultural soils) the principal ionic species in the soil are $H_2PO_4^-$ and HPO_4^{-2}. The monovalent ion, $H_2PO_4^-$, would be dominant below pH 6.7; above this value the divalent ion, HPO_4^{-2}, would dominate. The trivalent form becomes more important than the monovalent ion above pH 9.0; however, even at pH 12, the concentration of HPO_4^{-2} is still relatively greater than the concentration of PO_4^{-3}. Obviously, all phosphate reaction systems will be influenced by the hydrogen-ion activity in the reaction system.

Research to date indicates that the reaction mechanisms responsible for phosphorus fixation are of three general types:

(1) adsorption;

(2) isomorphic replacement; and

(3) double decomposition reaction involving solubility-product relationships.

Adsorption. The adsorption phenomenon is due to the attraction or repulsion between a solid surface and, in this case, a solution. This attraction or repulsion is a result of interaction between fields of force emanating from the surface of the adsorbent and the ions of the adsorbate. (Adsorption is discussed in the article by Bailey and White, 1964.) In this case, the liquid phase corresponds to the soil solution; the solid phase corresponds to the clay minerals, oxides and hydroxides of iron and aluminum, and the humic component of the soil organic matter.

Adsorption reactions may be classified generally into two types: (1) chemical adsorption and (2) physical adsorption. Both types may be characterized by the Freundlich adsorption isotherm or by the Langmuir adsorption isotherm.

Adsorption has been suggested as one of the mechanisms responsible for the fixation of phosphorus by soils, but the mechanism has not been clearly defined or described. In many cases, investigators have called the uptake of phosphorus by the soil "adsorption", whereas no direct evidence has substantiated this. To ascertain unequivocally whether true adsorption occurs, the problem should be studied by infrared and nuclear magnetic resonance spectroscopy.

The amount of phosphorus taken up by soils is proportional to the concentration of phosphorus initially present. Davis (1935) and Kurtz et al. (1946) showed that the fixation of phosphorus by soil could be described by the Freundlich adsorption isotherm, $\frac{x}{m} = kc^{\frac{1}{n}}$. Low and Black (1950) and Mallons and Barkoff (1953) showed that fixation of phosphorus at lower concentrations by kaolinite followed the Freundlich adsorption isotherm. Fisher (1922) pointed out that agreement of data with the results of the Freundlich adsorption isotherm cannot be considered as a criterion of adsorption. Kalthoff (1922) has shown that the Freundlich adsorption isotherm can represent exchange reactions when applied to ions, and it was pointed out by Hsu and Rennie (1962a) that the Langmuir adsorption isotherm has certain limitations when applied to ions in solution. Fixation of phosphorus by calcium carbonate and by heterogenous soil systems has been shown to conform with the Langmuir adsorption isotherm; this has been taken as absolute evidence of adsorption (Cole et al., 1953; Fried and Shapiro, 1956; Olson and Watanabe, 1957; Rennie and McKercher, 1959; Weir and Soper, 1962; and Woodruff and Kamprath, 1965).

The Langmuir adsorption isotherm was initially based on the assumptions that gas particles move in free space and that no force other than the attraction of solids interfered with their kinetic movement. However, the kinetic movement of the phosphate ion in an aqueous solution is affected by other ions. The Langmuir adsorption isotherm is valid only when the interfering force, due to interacting ions, is negligible. In a phosphate-aluminum hydroxide system, the activity of the aluminum ions (interfering force) is negligible above pH 5.

If phosphorus is adsorbed by the solid phase, or if other reactions occur, a reaction rate study would indicate whether adsorption is the sole reaction mechanism. Hsu and Rennie (1962a), in a study of the fixation of phosphorus by X-ray amorphous "aluminum hydroxide" in the pH range of 3.8 to 7, found that the initial reaction was completed within 30 minutes, and the authors attributed this to adsorption. However, this reaction was followed by a slow decomposition-precipitation process. Low and Black (1947), in a study of phosphorus fixation by kaolinite, concluded that the short-time reaction (1 1/2 to 3 hours) and low concentration (up to 0.0016 M) were probably adsorption reactions; other reactions dominated at higher concentration (1.0 M) and after longer contact (8 to 11 days).

Isomorphic Replacement. (1) Isomorphic replacement of hydroxyl or silicate anions from the crystal--such a reaction could be called anion exchange; this reaction involves silicate minerals such as the clay minerals and possibly the hydrated oxides of iron and aluminum, where the phosphate ion would substitute for hydroxyl ions under normally acid conditions (Mattson, 1930; Scarseth, 1935; Kelley and Midgley, 1943; Coleman, 1945; Low and Black, 1947; Swenson et al., 1949). Evidence for this reaction to occur is based on the following observations:

(a) Clay suspension and a phosphorus solution of similar pH are mixed and an increase in pH (due to increase in the hydroxyl ion concentration) accompanies the disappearance of phosphorus ions from solution.

(b) Phosphate ions fixed by soils can be displaced to some extent by hydroxyl, fluoride, silicate, and arsenate anions, thus implying anion exchange.

(c) Phosphorus fixation by soil colloids increases the amount of silicon in the supernatant solution.

A general reaction, representing the fixation of phosphorus by minerals under acid conditions and considering all of the fixing agents as having a replaceable OH^-, is as follows:

$$\boxed{\begin{array}{l}\text{Colloid}\\ \text{Micelle}\end{array}}\!-OH + \underset{\text{Solution}}{H_2PO_4^-} \longrightarrow \boxed{\begin{array}{l}\text{Colloid}\\ \text{Micelle}\end{array}}\!-\underset{\text{Fixed}}{H_2PO_4} + OH^-$$

It seems possible that adsorbed phosphorus could be transformed subsequently to a hydroxyl- or silicon-ion by isomorphic replacement in the crystal.

(2) Crystallization of new compounds. Low and Black (1947) showed that the fixation of phosphorus by kaolinite involved an actual breakdown of the silicate mineral into aluminum and silicate ions in accordance with the solubility-product principle. They also showed that the phosphorus precipitated the aluminum, resulting in the formation of a basic aluminum phosphate. By use of electron microscopy and X-ray diffraction techniques, Kittrick and Jackson (1955) showed that kaolinite will "dissolve" in the presence of phosphate at 90° C and that an aluminum phosphate is formed, leaving no trace of kaolinite after a reaction period of 31 days. Reifenberg and Buchwold (1954) demonstrated that treatment of both soils and clay minerals with excess phosphate resulted in lattice decomposition and formation of new products.

Recent work on the identification of decomposition products of phosphorus-silicate-minerals reaction products and the reaction of various fertilizers with soils has partially indicated the nature of the reaction products. Using chemical, optical, and X-ray diffraction methods, Haseman, et al. (1958) identified some of the crystalline products produced by interaction of phosphate with illite, kaolinite, montmorillonite, goethite, and limonite. The products were members of an isomorphic series with the general composition $[(H, K, Na, NH_4)_3\ x\ (FeAl)_3^x PO_4 \cdot nH_2O$, where x is greater than zero but less than 3. Other products were identified as members of the variscite-strengite isomorphic series--(Al, Fe)-$PO_4 \cdot 2H_2O$ (x + y = 1).

Major initial reaction products of monoammonium and diammonium phosphate solutions after 10 days in a fine sandy loam (pH 7.7; 6.6% $CaCO_3$; 6 ppm $NaHCO_3$ extractable phosphorus) appeared to be dicalcium phosphate dihydrate and hydroxyapatite (Beaton et al, 1963).

Some crystalline material of the variscite-strengite isomorphic series was found to be the ultimate product of phosphorus applied to acid soils (Wright and Peech, 1960).

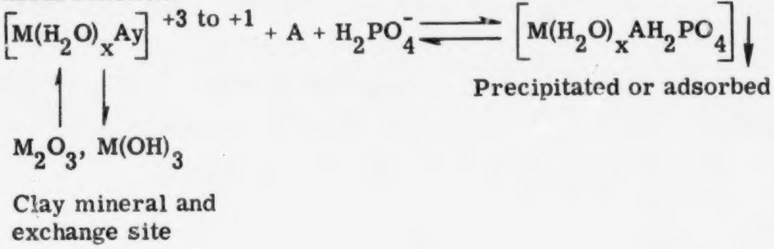
In the absence of K and NH_4, dissolution of gibbsite (aluminum hydroxide in an acidic aqueous solution of H_3PO_4 and $CaH_4(PO_4)_2$ precipitated a mixture of $CaHPO_4$, $CaAl(HPO_4)_2$ and amorphous material (Taylor et al., 1964); while reaction of goethite ($Fe_2O_3 \cdot H_2O$) with the same acidic solution of H_3PO_4 and $CaH_4(PO_4)_2$ precipitated $H_4CaFe_2(PO_4)_2$ and amorphous $FePO_4$.

Reaction of KPO_3 with $CaCO_3$ at a pH of 6 to 9 produced mainly hydroxyapatite, but $Ca_8H_2(PO_4)_6$ or $CaHPO_42H_2O$ were also formed, especially at pH 6 (Cecconi and Ristori, 1964).

From a consideration of solubility-product relationships, it appears that fixation of phosphorus should occur through precipitation with iron, aluminum, and calcium. In certain cases, precipitation with manganese may also be important. However, the question remains as to which reactions are the more important under differing environmental conditions of soil acidity, initial phosphorus concentration, clay mineral type, etc.

Hemwall (1957a), after reviewing research on phosphorus fixation, concluded that:

(a) Phosphorus fixation in acid soil resulted primarily from the formation of aluminum and iron compounds of the nature $M(H_2O)_3(OH)_2H_2PO_4$; M stands for the iron or aluminum cations. The sources are the aluminum- and iron-containing soil minerals including clay minerals (ion source as an exchangeable cation, or from decomposition of alumino-silicates). Under certain conditions, the phosphate-reaction products form a precipitate; while under a different set of conditions, they are adsorbed or formed as a result of a surface reaction. Whether the compound is formed on the surface of a soil mineral or is precipitated, the compounds formed and the mechanism of reaction appear to be essentially the same; that is, iron and alumninum compounds and clay minerals both fix phosphorus by the same method. The overall fixation of phosphorus by acid soils can be visualized by the following general reaction:



$$\left[M(H_2O)_xAy\right]^{+3\text{ to }+1} + A + H_2PO_4^- \rightleftharpoons \left[M(H_2O)_xAH_2PO_4\right]\downarrow$$

Precipitated or adsorbed

$$\updownarrow$$

M_2O_3, $M(OH)_3$

Clay mineral and
exchange site

where M stands for the cations of iron or aluminum and A stands for oxide or hydroxide.

(b) Phosphorus fixation in calcareous and alkaline soils is due to the formation of insoluble phosphate compounds in a solid solution series. Also, in certain instances, phosphorus can be fixed by the Al^{+3} or $Al(OH)_3$ in the clay fraction of alkaline soils, the extent of fixation is affected by the other cations present.

More recent research results have verified Hemwall's conclusions. Results indicate that aluminum is more important than iron in phosphorus fixation (Leaver and Russell, 1957; Sani and MacLean, 1965). Leaver and Russell studied the use of blocking agents to measure the relative importance of iron and aluminum oxides in sorption of phosphorus by acid soils. The "blocking agents" used included potassium ferrocyanide, selenious acid, quinalizarin, oxine, cupferron, alizarin, and Aluminon. It was found that the power to fix phosphorus in both the soils containing hydrated oxides and hydroxides was reduced with the "blocking agents," due to the formation of insoluble or un-ionized compounds containing iron and aluminum ions. Interestingly, the soil and oxide and hydroxides "fix" more blocking agent than was evidenced by the decrease in phosphorus fixation. The authors believed that it is not possible to fix a sufficient amount of blocking agent to eliminate phosphorus fixation entirely.

Blanchet (1959a) showed that $Fe(OH)_3$, and especially $Al(OH)_3$, possessed a greater capacity to fix phosphate ions than $CaCO_3$ or the clay minerals, kaolinite and montmorillonite.

Using isotopic dilution, Blanchet (1959b) studied the reaction of a colloidal suspension of $Fe(OH)_3$ in 0.01N sodium acetate with increasing concentrations of Na_2HPO_4. He used an adsorption period of 5 months and an isotopic dilution period of 3 days. He concluded that fixation of phosphorus is similar to adsorption and is not due to the precipitation of an iron phosphate.

Double Decomposition Reaction Involving Solubility Relations. Hsu and Rennie (1962a) derived a unified equation for the adsorption and precipitation of phosphate in an aluminum system (the aluminum system consisted of X-ray amorphous "aluminum hydroxides"). The equation was based on the assumptions that adsorption and precipitation result from the chemical union of aluminum with phosphate and that the adsorption equilibrium is related to the solubility of aluminum phosphate. The equation, as given below, was derived from: (1) the solubility of aluminum phosphate $\left[Al(OH)_2H_2PO_4\right]$, as defined by $K_1 = (Al^{+3})(H_2PO_4^-)(OH)_2$ and (2) the adsorption of phosphate by $Al(OH)_3$ as described by $R\text{-}OH + H_2PO_4 \rightleftharpoons RH_2PO_4 + OH^-$; where R is the radical of the $Al(OH)_3$ colloid, R-OH is the potential site for the adsorbing phosphates, and $R\text{-}H_2PO_4$ is the adsorbed phosphate. The equation is:

$$K_1 = \left\{ \frac{(R\text{-}OH)}{(R\text{-}H_2PO_4)\ (OH^-)^3} + (Al^{+3}) \right\} (H_2PO_4^-)\ (OH^-)_2$$

The equation suggests that the presence of phosphorus in the soil solution (in a leachable form) is governed by the total activity of ions that can fix phosphate (i.e., the aluminum in the system). Thus the activity of the aluminum in determining the solubility of aluminum phosphate should include both its activity on the surface and that in solution. It should be possible to show that iron would react in a similar manner. In general, aluminum would probably be more important in the fixation of phosphorus than iron because aluminum is more abundant structurally in alumino-silicates and can thus become exchangeable under acid conditions due to autotransformation of the layer-lattice silicate by the hydronium ion. This can be represented by the following:

$$K_2\ (\overset{VI}{Al_4})\ (\overset{IV}{Si_6Al_2})\ (OH)_4\ O_{20} + 3H_3O^+ \rightarrow K_2\ (\overset{VI}{Al_3H_3})\ (\overset{IV}{Si_6Al_2})\ (OH)_4\ O_{20} + Al^{+3} + 3H_2O$$

(Muscovite)

The aluminum ion can then either be exchanged for another ion on the cation exchange complex or hydrate to $\left[Al(H_2O)_6\right]^{+3}$, then hydrolyze to the monomer $\left[Al(OH)(H_2O)_5\right]^{+2} + H_3O^+$, and afterwards polymerize. The exact nature of the resulting polymer varies according to the pH (the $\frac{OH}{Al}$ ratio). Hsu and Rich (1960) postulated that $\left[Al_6(OH)_{12}(H_2O)_{12}\right]^{+6}$ is formed and adsorbed by clays. Jackson (1963) discusses the alumino-hexa-hydronium ion, its role in (1) soil acidity and liming, (2) cation exchange of soils and clays, and (3) the anion retention by soils.

From a study on the availability and utilization of phosphates in Hawaiian soils, DeDatta (1964) concluded that the tendency of a soil system to fix phosphorus depends, in decreasing order of importance, on the presence of the following: amorphous hydrated oxides, goethite, gibbsite, kaolinite, and 2:1 clays. Addition of lime (decreasing soil acidity) to a pH of 5.5 resulted in the precipitation of a large amount of active aluminum and in an increased phosphorus solubility.

The work of Chang and Jackson (1958) indicated that chemical weathering in soils can change the state or form of phosphorus in the soil. One effect of liming on the form of phosphorus in soil is to favor the formation of calcium phosphate and the release (through the repression of aluminum and iron) of phosphate from the solid aluminum and iron phosphates. The importance of aluminum over iron in phosphorus fixation was shown by Bromfield (1964). Using a biological reduction method to remove iron, but not aluminum, the phosphorus fixation capacity of three acid soils was not removed; whereas, when aluminum was removed, the phosphorus sorptive capacity decreased.

Olsen and Watanabe (1957) found that phosphorus sorption was closely related to surface area, that acid soils retained more phosphorus per unit surface than alkaline soils, and that acid soils also held the phosphorus with a greater bonding strength than the alkaline-soils did.

On the basis of solubility product calculations, most investigators have assumed that in the soils the ion form would be $H_2PO_4^-$ and that it was thus fixed as this ion. The infrared work of Gastuche et al. (1963) indicated that this is not always the case; the ionic form may be a function of the substrate and the concentration of the phosphorus in a solution. Treatment of iron and aluminum compounds with 0.01$\underline{M}$ KH_2PO_4 resulted in the fixation of the PO_4^- anion; while reaction of aluminum compounds with 1 $\underline{M}$ KH_2PO_4 resulted in the fixation of $H_2PO_4^-$.

The effect of exchangeable aluminum in phosphorus fixation was further emphasized by Coleman et al. (1960). Phosphorus sorbed by a subsoil was correlated with exchangeable aluminum; the equation was: $Y = 0.077 + 0.703X$, where x = amount of exchangeable aluminum. Removal of exchangeable aluminum by leaching with a KCl solution reduced phosphorus sorption except in those soils where the level of exchangeable aluminum was low or where the iron and aluminum oxide content was high. The amount of phosphorus was stoichiometrically equal to the concentration of exchangeable aluminum under conditions where aluminum hydrolysis is favored.

The mechanism of lattice decomposition and resultant release of aluminum and the formation of aluminum phosphate was supported by the work of Tamini et al. (1964). Reaction of the clay minerals, montmorillonite and kaolinite, with solutions of $(NH_4)_2HPO_4$ at a low PH resulted in diminished characteristic X-ray diffraction peaks for these two minerals. The authors believed that the reaction product was taranakite ($K_2Al_6\left[PO_4\right]_6\left[OH\right]_2 \cdot 18\ H_2O$).

Organic materials have been shown to influence phosphorus sorption on clay minerals and soils (Fokin and Chistova, 1964). The authors believed that the fixation of phosphorus by kaolinite and by soils coated with organic material is as follows: the initial sorption of phosphorus in low concentration is by exchange with a film of organo-mineral gel surrounding the particles comprising the mineral fraction of the soil; while at a high phosphorus concentration, the film becomes saturated with phosphorus; and at still higher concentrations, the phosphorus diffuses through the film and reacts with the mineral components of the soil.

It does not appear in all cases that the aluminum content and the presence of aluminum-containing minerals are the most important factors in phosphorus fixation. Demolon and Muller (1954) from a study of phosphate (PO_4) diffusion, initially present as $CaH_4(PO_4)_2$, in alumino- and ferrosilicates at various pH levels, found that there was less diffusion in the iron system than in the alumino-silicate system. The experiment again pointed out the major effect of acidity on phosphorus fixation. At pH 3 to 4.5, the phosphate precipitated in immediate contact with the phosphorus granule; at pH 5 to 6.5, rapid migration without precipitation occurred; while at a pH greater than 7, diffusion resulted in a series of concentric rings of precipitated phosphate. Humic acid added to the gels kept the phosphate in a more water-soluble form.

Organic Phosphorus Fixation Mechanisms

It is quite conceivable that some phosphorus in waste effluents might be present in the organic form; therefore, information on whether organic phosphorus would be removed from a percolating solution is important.

A portion of the total phosphorus in soils is organic in nature. Only a minor part of the organic phosphorus of soils appears to be present as nucleic acids and phospholipids. Inositol phosphates form the major part of the soil organic phosphorus thus far identified.

Of particular importance is the evidence cited by Bower (1949) that nucleic acids are adsorbed by clay minerals. Such adsorption was greater on bentonite than on kaolinite, and the magnitude increased with decreasing pH. One would expect that the greater adsorption would be by bentonite because of its higher exchange capacity; also with increasing acidity, the basicity of the compounds increases.

Further work on the nature and character of the adsorption of nucleic acids by clay minerals was carried out by Goring and Bartholomew (1952). These authors showed that the reaction was: (1) rapid, (2) temperature dependent, (3) pH dependent (increased adsorption with decreasing pH), (4) cation dependent (greater adsorption when calcium or magnesium was present on the exchange sites, rather than sodium or potassium), (5) reversible in nature, (6) linearly related to the cation exchange capacity of the various clay fractions and (7) nucleic acids at least partially adsorbed interlamellarly. Further, the authors concluded that the nucleic acids were adsorbed by a cation exchange reaction and also through the orthophosphate groups.

Jackman and Black (1951) found that iron and aluminum salts of inositol phosphates were very insoluble in an acidic solution above pH 2 to 3. Because the pH solubility curves are very similar to the inorganic orthophosphates, organic compounds such as phytin and their derivatives should be fixed in soils as insoluble salts of aluminum, iron, and calcium in a manner similar to inorganic phosphates.

It appears that soil minerals other than clay minerals adsorb inositol phosphates. Anderson and Arlidge (1962) found that boehmite, ferric oxide gel, and a soil high in sesquioxides all adsorbed β-glycerophosphate. In general, the extent of adsorption was related to the number of phosphate groups in the molecule; the higher the number of phosphate groups in the molecule, the greater was the degree of adsorption. There was also a relationship between pH, nature of adsorbent, and extent of adsorption. Maximum adsorption of inositol hexaphosphate was found in two distinctly acid media (pH 3 to 4) and in an acid concentration of about 0.1$\underline{N}$. Montmorillonite was most reactive at pH 4. The author attributed this to maximum content of active aluminum. Ferric oxide gel removed a considerable amount of inositol phosphate from a strongly acid solution, presumably partly by adsorption and partly by precipitation of insoluble salts or complexes of the ester. In a less acid medium (pH 3 - 4), the gel was relatively ineffective in removing the organic phosphate. Boehmite was highly reactive over a wide range of pH. From pH 4 down to a concentration of 4$\underline{N}$ with respect to HCl, greatest adsorption occurred at pH of approximately 1. Boehmite adsorbed more inositol mono-, di-, and tri-phosphates as well as β-glycerophosphate in 1$\underline{N}$ HCl than in 0.1$\underline{N}$ HCl. X-ray diffraction did not indicate the presence of an ordered clay-organic complex.

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Glossary of Selected Soil Science Terms

A

A horizon – See soil horizon.

ABC soil – A soil with a distinctly developed profile, including A, B, and C horizons.

AC soil – A soil having a profile containing only A and C horizons with no clearly developed B horizon.

accelerated erosion – See erosion (ii)

acid soil – A soil with a preponderance of hydrogen ions, and probably of aluminum, in proportion to hydroxyl ions. Specifically, soil with a pH value <7.0. For most practical purposes a soil with a pH value <6.6. The pH values obtained vary greatly with the method used and, consequently, there is no unanimous agreement as to what constitutes an acid soil. (The term is usually applied to the surface layer or to the root zone unless specified otherwise.)

acidity, active – The activity of hydrogen ion in the aqueous phase of a soil. It is measured and expressed as a pH value.

acidity, free – The titratable acidity in the aqueous phase of a soil. This may be expressed in milliequivalents per unit mass of soil or in other suitable units.

acidity, potential – The amount of exchangeable hydrogen ion in a soil that can be rendered free or active in the soil solution by cation exchange. Usually expressed in milliequivalents per unit mass of soil.

actinomycetes – A general term applied to a group of organisms intermediate between the bacteria and the true fungi that usually produce a characteristic branched mycelium and sporulate by segmentation of the entire mycelium or, more commonly, by segmentation of special terminal hyphae. Any organism belonging to the order of Actinomycetales.

adsorption complex – The group of substances in soil capable of adsorbing other materials. Organic and inorganic colloidal substances form the greater part of the adsorption complex; the noncolloidal materials, such as silt and sand, exhibit adsorption but to a much lesser extent than the colloidal materials.

aerate – To impregnate with a gas, usually air.

aeration, soil – The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is very similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen than the atmosphere above the soil. The rate of aeration depends largely on the volume and continuity of pores within the soil.

aeration porosity – See air porosity.

aerobic – (i) Having molecular oxygen as a part of the environment. (ii) Growing only in the presence of molecular oxygen, as aerobic organisms.
(iii) Occurring only in the presence of molecular oxygen (said of certain chemical or biochemical processes such as aerobic decomposition).

agronomy – A specialization of agriculture concerned with the theory and practice of field-crop production and soil management. The scientific management of land.

air-dry – (i) The state of dryness (of a soil) at equilibrium with the moisture content in the surrounding atmosphere. The actual moisture content will depend upon the relative humidity and the temperature of the surrounding atmosphere.
(ii) To allow to reach equilibrium in moisture content with the surrounding atmosphere.

air porosity – The proportion of the bulk volume of soil that is filled with air at any given time or under a given condition such as a specified moisture tension. Usually the large pores; that is, those drained by a tension of less than approximately 100 cm of water. See Moisture Tension.

alkali soil – (i) A soil with a high degree of alkalinity (pH of 8.5 or higher) or with a high exchangeable sodium content (15% or more of the exchange capacity), or both. (ii) A soil that contains sufficient alkali (sodium) to interfere with the growth of most crop plants. See saline-alkali soil and sodic soil.

alkaline soil – Any soil that has a pH >7.0. See reaction, soil.

alkalization – The process whereby the exchangeable sodium content of a soil is increased.

Alluvial soil – (i) A soil developing from recently deposited alluvium and exhibiting essentially no horizon development or modification of the recently deposited materials. (ii) When capitalized the term refers to a great soil group of the azonal order consisting of soils with little or no modification of the recent sediment in which they are forming (indicated by absence of a B horizon).

alpha humus – A mixture of dark-colored organic substances of indefinite chemical composition extracted from the soil by dilute alkali and precipitated by making the extract strongly acid.

amendment, soil – (i) An alteration of the properties of a soil, and thereby of the soil, by the addition of substances such as lime, gypsum, sawdust, etc., to the soil for the purpose of making the soil more suitable for the production of plants. (ii) Any such substance used for this purpose. Strictly speaking, fertilizers constitute a special group of soil amendments.

ammonification – The biochemical process whereby ammoniacal nitrogen is released from nitrogen-containing organic compounds.

ammonium fixation – The adsorption or absorption of ammonium ions by the mineral or organic fractions of the soil in a manner that they are relatively insoluble in water and relatively unexchangeable by the usual methods of cation exchange.

anaerobic – (i) The absence of molecular oxygen. (ii) Growing in the absence of molecular oxygen (such as anaerobic bacteria). (iii) Occurring in the absence of molecular oxygen (as a biochemical process).

anion-exchange capacity – The sum total of exchangeable anions that a soil can adsorb. Expressed as milliequivalents per 100 grams of soil (or of other adsorbing material such as clay).

antibiotic – A substance produced by one species of organism that, in low concentrations, will kill or inhibit growth of certain other organisms.

artificial manure – See compost. (In European usage may denote commercial fertilizers.)

association, soil – See soil association.

autochthonous flora – That portion of the microflora presumed to subsist on the more resistant soil organic matter and little affected by the addition of fresh organic materials. Contrast with zymogenous flora.

autotrophic – Capable of utilizing carbon dioxide or carbonates as the sole source of carbon and obtaining energy for the reduction of carbon dioxide and for other life processes from the oxidation of inorganic elements or compounds such as iron, sulfur, hydrogen, ammonium, and nitrites, or from radiant energy. Contrast with heterotrophic.

available nutrient – That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants. ("Available" should not be confused with "exchangeable.")

available water – The portion of water in a soil that can be readily absorbed by plant roots. Considered by most workers to be that water held in the soil against a pressure of up to approximately 15 bars. See field capacity and moisture tension.

azonal soils – Soils without distinct genetic horizons. A soil order.

B

B horizon – See soil horizon.

badland – A land type generally devoid of vegetation and broken by an intricate maze of narrow ravines, sharp crests, and pinnacles resulting from serious erosion of soft geologic materials. Most common in arid or semiarid regions. A miscellaneous land type.

bar – A unit of pressure equal to one million dynes per square centimeter.

base-saturation percentage – The extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen. It is expressed as a percentage of the total cation-exchange capacity.

BC soil – A soil profile with B and C horizons but with little or no A horizon.

Selected terms from the "Glossary of Soil Science Terms" originally published in Soil Science Society of America Proceedings, Volume 29, p. 330-351 (1965).

bedrock – The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feet.

bench terrace – See terrace.

biological immobilization – See immobilization and biological interchange.

biological interchange – The interchange of elements between organic and inorganic states in a soil or other substrate through the agency of biological activity. It results from biological decomposition of organic compounds and the liberation of inorganic materials (mineralization); and, from the utilization of inorganic materials in the synthesis of microbial tissue (immobilization). Both processes commonly proceed continuously in soils.

biological mineralization – See mineralization and biological interchange.

biosequence – A sequence of related soils that differ, one from the other, primarily because of differences in kinds and numbers of soil organisms as a soil-forming factor.

bisect – A profile of plants and soil showing the vertical and lateral distribution of roots and tops in their natural position.

Black Earth – A term used by some as synonymous with "Chernozem;" by others (in Australia) to describe self-mulching black clays.

bleicherde – The light-colored, leached A2 horizon of Podzol soils.

blocky soil structure – See soil structure.

blown-out-land – Areas from which all or almost all of the soil and soil material has been removed by wind erosion. Usually barren, shallow depressions with a flat or irregular floor consisting of a more resistant layer and/or an accumulation of pebbles, or a wet zone immediately above a water table. Usually unfit for crop production. A miscellaneous land type.

blowout – A small area of blown-out land.

bog iron ore – Impure ferruginous deposits developed in bogs or swamps by the chemical or biochemical oxidation of iron carried in solution.

Bog soil – A great soil group of the intrazonal order and hydromorphic suborder. Includes muck and peat.

border-strip irrigation – See irrigation methods.

bottomland – See flood plain.

breccia – A rock composed of coarse angular fragments cemented together.

broad-base terrace – See terrace.

Brown Earths – Soils with a mull horizon but having no horizon of accumulation of clay or sesquioxides. (Generally used as a synonym for "Brown Forest soils" but sometimes for similar soils acid in reaction.)

Brown Forest soils – A great soil group of the intrazonal order and calcimorphic suborder, formed on calcium-rich parent materials under deciduous forest, and possessing a high base status but lacking a pronounced illuvial horizon. (A much more narrow group than the European Brown Forest or Braunerde.)

Brown Podzolic soils – A zonal great soil group similar to Podzols but lacking the distinct A2 horizon characteristic of the Podzol group. (Some American soil taxonomists prefer to class this soil as a kind of Podzol and not as a distinct great soil group.)

Brown soils – A great soil group of the temperate to cool arid regions, composed of soils with a brown surface and a light-colored transitional subsurface horizon over calcium carbonate accumulation.

Brunizem – Synonymous with Prairie soils.

buffer compounds, soil – The clay, organic matter, and compounds such as carbonates and phosphates which enable the soil to resist appreciable change in pH.

bulk density, soil – The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to constant weight at 105C.

bulk specific gravity – The ratio of the bulk density of a soil to the mass of unit volume of water.

bulk volume – The volume, including the solids and the pores, of an arbitrary soil mass.

Buried soil – Soil covered by an alluvial, loessal, or other deposit, usually to a depth greater than the thickness of the solum.

C

C horizon – See soil horizon.

calcareous soil – Soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when treated with cold 0.1N hydrochloric acid.

calciphytes – Plants that require or tolerate considerable amounts of calcium or, are associated with soils rich in calcium.

Caliche – (i) A layer near the surface, more or less cemented by secondary carbonates of calcium or magnesium precipitated from the soil solution. It may occur as a soft thin soil horizon, as a hard thick bed just beneath the solum, or as a surface layer exposed by erosion (see croute calcaire). Not a geologic deposit. (ii) Alluvium cemented with sodium nitrate, chloride, and/or other soluble salts in the nitrate deposits of Chile and Peru.

capillary fringe – A zone just above the water table (zero gauge pressure) that remains almost saturated. (The extent and the degree of definition of the capillary fringe depends upon the size-distribution of pores.)

capillary potential – See soil water.

carbon cycle – The sequence of transformations whereby carbon dioxide is fixed in living organisms by photosynthesis or by chemosynthesis, liberated by respiration and by the death and decomposition of the fixing organism, used by heterotrophic species, and ultimately returned to its original state.

carbon-nitrogen ratio – The ratio of the weight of organic carbon to the weight of total nitrogen in a soil or in organic material. It is obtained by dividing the percentage of organic carbon (C) by the percentage of total nitrogen (N).

category – Any one of the ranks of the system of soil classification in which soils are grouped on the basis of their characteristics.

catena – A sequence of soils of about the same age, derived from similar parent material, and occurring under similar climatic conditions, but having different characteristics due to variation in relief and in drainage. See clinosequence and toposequence.

cation exchange – The interchange between a cation in solution and another cation on the surface of any surface-active material such as clay colloid or organic colloid.

cation-exchange capacity – The sum total of exchangeable cations that a soil can adsorb. Sometimes called "total-exchange capacity," "base-exchange capacity," or "cation-adsorption capacity." Expressed in milliequivalents per 100 grams of soil (or of other adsorbing material such as clay).

cemented – Indurated; having a hard, brittle consistency because the particles are held together by cementing substances such as humus, calcium carbonate, or the oxides of silicon, iron, and aluminum. The hardness and brittleness persist even when wet.

check-basin irrigation – See irrigation methods.

chemically precipitated phosphorus – Relatively insoluble phosphorus compounds resulting from reactions between constituents in solution to form chemically homogeneous particles of the solid phase. Examples are: calcium and magnesium phosphates which are precipitated above a pH of about 6.0 to 6.5 (if calcium and magnesium are present); and, iron and aluminum phosphates which are precipitated below a pH of about 5.8 to 6.1 at which many iron and aluminum compounds are soluble. A form of fixed phosphate. See chemisorbed phosphorus.

chemisorbed phosphorus – Phosphorus adsorbed or precipitated on the surface of clay minerals or other crystalline materials as a result of the attractive forces between the phosphate ion and constituents in the surface of the solid phase.

Chernozem – A zonal great soil group consisting of soils with a thick, nearly black or black, organic matter-rich A horizon high in exchangeable calcium, underlain by a lighter colored transitional horizon above a zone of calcium carbonate accumulation; occurs in a cool subhumid climate under a vegetation of tall and midgrass prairie.

chert – See coarse fragments.

Chestnut soil – A zonal great soil group consisting of soils with a moderately thick, dark-brown A horizon over a lighter colored horizon that is above a zone of calcium carbonate accumulation.

chisel, subsoil – A tillage implement with one or more cultivator-type feet to which are attached strong knifelike units used to shatter or loosen hard, compact layers, usually in the subsoil, to depths below normal plow depth. See subsoiling.

chroma – The relative purity, strength, or saturation of a color; directly related to the dominance of the determining wavelength of the light and inversely related to grayness; one of the three variables of color. See Munsell color system, hue, and value, color.

chronosequence – A sequence of related soils that differ, one from the other, in certain properties primarily as a result of time as a soil-forming factor.

class, soil – A group of soils having a definite range in a particular property such as acidity, degree of slope, texture, structure, land-use capability, degree of erosion, or drainage. See soil texture and soil structure.

classification, soil – The systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics and subdivisions on the basis of more detailed differences in specific properties. In the United States the following system has been used for a number of years (from Soil Survey Staff, SCS, USDA. 1960. Soil classification: A comprehensive system – 7th approximation. p. 9. U. S. Government Printing Office, Washington):

Order	Suborder	Great soil groups
Zonal soils	1) Soils of the cold zone	Tundra soils
	2) Light-colored soils of arid regions	Desert soils Red Desert soils Sierozem Brown soils Reddish Brown soils
	3) Dark-colored soils of semiaric, subhumid, and humid grass-lands	Chestnut soils Reddish Chestnut soils Chernozem soils Prairie soils Reddish Prairie soils
	4) Soils of the forest-grassland transition	Degraded Chernozem Noncalcic Brown or Shantung Brown soils
	5) Light-colored podzolized soils of the timbered regions	Podzol soils Gray Wooded, or Gray Podzolic soils* Brown Podzolic soils Gray-Brown Podzolic soils* Red-Yellow Podzolic soils
	6) Lateritic soils of forested warm-temperate and tropical regions	Reddish-Brown Lateritic soils* Yellowish-Brown Lateritic soils Laterite soils*
Intrazonal soils	1) Halomorphic (Saline and alkali) soils of imperfectly drained arid regions and littoral deposits	Solonchak, or Saline soils Solonetz soils Soloth soils
	2) Hydromorphic soils of marshes, swamps, seep areas, and flats	Humic Gley soils* (includes Wiesenboden) Alpine Meadow soils Bog soils Half-Bog soils Low-Humic Gley soils* Planosols Ground-Water Podzol soils Ground-Water Laterite soils
	3) Calcimorphic soils	Brown Forest soils (Braunerde) Rendzina soils
Azonal soils		Lithosols Regosols (includes Dry Sands) Alluvial soils

*New or recently modified great soil groups.

The following scheme has been proposed for adoption as the official system in the United States (from Soil Survey Staff, SCS, USDA, 1960. Soil classification: A comprehensive system – 7th approximation. p.13. U. S. Government Printing Office, Washington):

Present order	Approximate equivalents
1) Entisols	Azonal soils, and some Low-Humic Gley soils
2) Vertisols	Grumusols
3) Inceptisols	Ando, Sol Brun Acide, some Brown Forest, Low-Humic Gley, and Humic Gley soils
4) Aridisols	Desert, Reddish Desert, Sierozem, Solonchak, some Brown and Reddish Brown soils, and associated Solonetz
5) Mollisols	Chestnut, Chernozem, Brunizem(Prairie), Rendzina, some Brown, Brown Forest, and associated Solonetz and Humic Gley soils
6) Spodosol	Podzols, Brown Podzolic soils, and Ground-Water Podzols
7) Alfisols	Gray-Brown Podzolic, Gray Wooded soils, Noncalcic Brown soils, Degraded Chernozem, and associated Planosols and some Half-Bog soils
8) Ultisols	Red-Yellow Podzolic soils, Reddish-Brown Lateritic soils of the USA, and associated Planosols and Half-Bog soils
9) Oxisols	Laterite soils, Latosols
10) Histosols	Bog soils

clay – (i) A soil separate consisting of particles <0.002 mm in equivalent diameter. See soil separates. (ii) A textural class. See soil texture.

clayey – Containing large amounts of clay or having properties similar to those of clay.

clay loam – A textural class. See soil texture.

clay mineral – (i) Naturally occurring inorganic crystalline material found in soils and other earthy deposits, the particles being of clay size; that is, <0.002 mm in diameter. (ii) Material as described under (i), but not limited by particle size.

claypan – A dense, compact layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry, and plastic and sticky when wet. Also, they usually impede the movement of water and air, and the growth of plant roots.

climatic index – A simple, single numerical value that expresses climatic relationships; for example, the numerical value obtained in Transeau's precipitation-evaporation ratio.

climax – A plant community of the most advanced type capable of development under, and in dynamic equilibrium with, the prevailing environment.

climosequence – A sequence of related soils that differ, one from the other, in certain properties primarily as a result of the effect of climate as a soil-forming factor.

clinosequence – A group of related soils that differ, one from the other, in certain properties primarily as a result of the effect of the degree of slope on which they were formed. See toposequence.

clod – A compact, coherent mass of soil ranging in size from 5 or 10 mm to as much as 8 or 10 inches; produced artificially, usually by the activity of man by plowing, digging, etc., especially when these operations are performed on soils that are either too wet or too dry for normal tillage operations.

coarse fragments – Rock or mineral particles >2.0 mm in diameter. The following names are used for coarse fragments in soils.*

Fragments†		Descriptive terms applied to fragments that have:		
Shape	Material	Diameters less than 3 inches	Diameters from 3 to 10 inches	Diameters more than 10 inches
rounded or subrounded	all kinds of rock	gravelly	cobbly	stony‡
irregular and angular	chert	cherty	coarse cherty	stony
	other than chert	angular	angular cobbly	stony
		Lengths up to 6 inches	Lengths from 6 to 15 inches	Lengths over 15 inches
thin and flat	limestone, sandstone, or schist	channery	flaggy	stony
	slate	slaty	flaggy	stony
	shale	shaly	flaggy	stony

*From: Soil Survey Staff, SCS, USDA. 1951. Soil survey manual, U. S. Dept. Agr. Handbook 18, p. 214. U. S. Government Printing Office, Washington.
†The adjectives describing fragments are also applied to lands and soils when they have significant amounts of such fragments. ‡"bouldery" is sometimes used when stones are larger than 24 inches.

coarse sand – See soil separates and soil texture.

coarse sandy loam – See soil texture.

coarse texture – The texture exhibited by sands, loamy sands, and sandy loams except very fine sandy loam. A soil containing large quantities of these textural classes (United States usage). See sand, sandy, and moderately-coarse texture.

cobblestone – Rounded or partially rounded rock or mineral fragments between 3 and 10 inches in diameter. See coarse fragments.

cobbly – Containing appreciable quantities of cobblestones. (Said of soil and of land. The term "angular cobbly" is used when the fragments are less rounded.) See coarse fragments.

colluvium – A deposit of rock fragments and soil material accumulated at the base of steep slopes as a result of gravitational action. See creep.

color – See Munsell color system.

columnar soil structure – See soil structure types.

complex, soil – See soil complex.

compost – Organic residues, or a mixture of organic residues and soil, that have been piled, moistened, and allowed to undergo biological decomposition. Mineral fertilizers are sometimes added. Often called "artificial manure" or "synthetic manure" if produced primarily from plant residues.

concentrated flow – The flowing of a rather large accumulated body of water over a relatively narrow course. It often causes serious erosion and gullying.

concretion – A local concentration of a chemical compound, such as calcium carbonate or iron oxide, in the form of a grain or nodule of varying size, shape, hardness, and color.

conductivity, hydraulic – See soil water.

consistency – (i) The resistance of a material to deformation or rupture. (ii) The degree of cohesion or adhesion of the soil mass. Terms used for describing consistency at various soil moisture contents are:

WET SOIL – nonsticky, slightly sticky, sticky, very sticky, nonplastic, slightly plastic, plastic, and very plastic.

MOIST SOIL – loose, very friable, friable, firm, very firm, and extremely firm.

DRY SOIL – loose, soft, slightly hard, hard, very hard, and extremely hard.

CEMENTATION – weakly cemented, strongly cemented, and indurated.

consistency constants – See liquid limit, plastic limit, and plasticity number.

corrugation – See irrigation methods.

cradle knoll – A small knoll formed by earth that is raised and left by an uprooted tree. (A microrelief term.)

creep – Slow mass movement of soil and soil material down relatively steep slopes primarily under the influence of gravity, but facilitated by saturation with water and by alternate freezing and thawing.

critical reaction – In biology that pH at which a biological process becomes too slow to measure or at which organisms die.

crotovina – A former animal burrow in one soil horizon that has been filled with organic matter or material from another horizon (also spelled "krotovina").

croute calcaire – Hardened caliche, often found in thick masses or beds overlain by only a few inches of earth. See caliche.

crumb – A soft, porous, more or less rounded ped from 1 to 5 mm in diameter. See soil structure types and soil structure classes.

crumb structure – A structural condition in which most of the peds are crumbs. See soil structure types.

crushing strength – The force required to crush a mass of dry soil or, conversely, the resistance of the dry soil mass to crushing. Expressed in units of force per unit area (pressure).

crust – A surface layer on soils, ranging in thickness from a few millimeters to perhaps as much as an inch, that is much more compact, hard, and brittle, when dry, than the material immediately beneath it.

crystal – A homogeneous inorganic substance of definite chemical composition bounded by plane surfaces that form definite angles with each other, thus giving the substance a regular geometrical form. See soil mineral.

crystal lattice – See lattice structure.

crystalline rock – A rock consisting of various minerals that have crystallized in place from magma. See igneous rock and sedimentary rock.

cultivation – A tillage operation used in preparing land for seeding or transplanting or later for weed control and for loosening the soil.

cyclic salt – Salt deposited on the soil by wind blowing off the sea or off inland salt lakes.

D

D layer – (Obsolete) An unconsolidated geological stratum, beneath the solum of some soils, that does not conform to the parent material from which the overlying soil was formed even though it may influence the genesis or behavior of the soil. See soil horizon.

Darcy's equation – See Darcy's law.

Darcy's law – (i) A law describing the rate of flow of water through porous media. (Named for Henry Darcy of Paris who formulated it in 1856 from extensive work on the flow of water through sand filter beds.) As formulated by Darcy the law is:

$$Q = kS \left(\frac{H + e}{e}\right),$$

where

Q is the volume of water passed in unit time,
S is the area of the bed,
e is the thickness of the bed,
H is the height of the water on top of the bed, and
"k is a coefficient depending on the nature of the sand" and for cases where the pressure "under the filter is equal to the weight of the atmosphere."

(ii) Generalization for three dimensions: The rate of viscous flow of water in isotropic porous media is proportional to, and in the direction of, the hydraulic gradient. (iii) Generalization for other fluids: The rate of viscous flow of homogeneous fluids through isotropic porous media is proportional to, and in the direction of the driving force.

decalcification – The removal of calcium carbonate or calcium ions from the soil by leaching.

decomposition – See mineralization.

deflation – The removal of fine soil particles from soil by wind.

deflocculate – (i) To separate the individual components of compound particles by chemical and/or physical means. (ii) To cause the particles of the disperse phase of a colloidal system to become suspended in the dispersion medium.

Degraded Chernozem – A zonal great soil group consisting of soils with a very dark brown or black A1 horizon underlain by a dark gray, weakly expressed A2 horizon and a brown B(?) horizon; formed in the forest-prairie transition of cool climates.

denitrification – The biochemical reduction of nitrate or nitrite to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.

deposit – Material left in a new position by a natural transporting agent such as water, wind, ice, or gravity, or by the activity of man.

Depression Podzol – Poorly drained depressional soils of the grassland and parkland regions of Canada with bleached A2 horizons and finer-textured B horizons. Also referred to as Bluff Podzol, Meadow Podzol, or Slough Podzol.

desert crust – A hard layer, containing calcium carbonate, gypsum, or other binding material, exposed at the surface in desert regions.

desert pavement – The layer of gravel or stones left on the land surface in desert regions after the removal of the fine material by wind erosion.

Desert soil – A zonal great soil group consisting of soils with a very thin, light-colored surface horizon, which may be vesicular and is ordinarily underlain by calcareous material; formed in arid regions under sparse shrub vegetation.

diatoms – Algae having siliceous cell walls that persist as a skeleton after death. Any of the microscopic unicellular or colonial algae constituting the class Bacillariaceae. They occur abundantly in fresh and salt waters and their remains are widely distributed in soils.

diatomaceous earth – A geologic deposit of fine, grayish siliceous material composed chiefly or wholly of the remains of diatoms. It may occur as a powder or as a porous, rigid material.

differential water capacity – See soil water.

direct counts – In soil microbiology any one of several methods of estimating the total number of microorganisms in a given mass of soil by direct microscopic examination.

disintegration – See physical weathering.

disperse – (i) To break up compound particles, such as aggregates, into the individual component particles. (ii) To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water.

dispersion medium – The portion of a colloidal system in which the disperse phase is distributed.

diversion dam – A structure or barrier built to divert part or all of the water of a stream to a different course.

double layer – In colloid chemistry, the electric charges on the surface of the disperse phase (usually negative), and the adjacent diffuse layer (usually positive) of ions in solution.

drag – The force retarding the flow of water or wind over the surface of the ground.

drain, to – (i) To provide channels, such as open ditches or drain tile, so that excess water can be removed by surface or by internal flow. (ii) To lose water (from the soil) by percolation.

drainage, excessive – Too much or too rapid loss of water from soils, either by percolation or by surface flow. Loss greater than that necessary to prevent the development of an anaerobic condition for any appreciable length of time.

drainage terrace – See terrace.

drain tile – Concrete or ceramic pipe used to conduct water from the soil.

dry aggregate – A compound or secondary soil particle that is not destroyed by dry sieving.

dryland farming – The practice of crop production in low-rainfall areas without irrigation.

dry-weight percentage – The ratio of the weight of any constituent (of a soil) to the oven-dry weight of the soil. See oven-dry soil.

duff mull – A type of forest humus transitional between mull and mor; H and F layers as well as the A1 horizon.

dust mulch – A loose, finely granular, or powdery condition on the surface of the soil, usually produced by shallow cultivation.

dy – Finely divided, partially decomposed organic material accumulated in peat soils in the transition zone between the peat and the underlying mineral material.

dynamometer – An instrument for measuring draft of tillage implements and for measuring resistance of soil to penetration by tillage implements.

E

ecology – The science that deals with the interrelations of organisms and their environment.

ectodynamomorphic soils – Soils with properties that have been produced or influenced mainly by factors other than parent material. See endodynamomorphic soils.

edaphic – (i) Of or pertaining to the soil. (ii) Resulting from or influenced by factors inherent in the soil or other substrate, rather than by climatic factors.

edaphology – The science that deals with the influence of soils on living things, particularly plants, including man's use of land for plant growth.

effective precipitation – That portion of the total precipitation which becomes available for plant growth.

electrokinetic potential – (i) In a colloidal system, the difference in potential between the immovable layer attached to the surface of the dispersed phase and the dispersion medium. (ii) The work done in bringing a unit charge from infinity to a reference point in the liquid layer attached to the solid phase in a colloidal system.

eluvial horizon – A soil horizon that has been formed by the process of eluviation. See illuvial horizon.

eluviation – The removal of soil material in suspension (or in solution) from a layer or layers of a soil. (Usually, the loss of material in solution is described by the term "leaching." See illuviation and leaching.

endodynamomorphic soils – Soils with properties that have been influenced primarily by parent material.

endotrophic – Nourished or receiving nourishment from within, as fungi or their hyphae receiving nourishment from plant roots in a mycorrhizal association.

enrichment culture – A technique in which environmental (including nutritional) conditions are controlled to favor the development of a specific organism or group of organisms.

equivalent diameter – In sedimentation analysis the diameter assigned to a nonspherical particle, it being numerically equal to the diameter of a spherical particle of the same density and velocity of fall.

equivalent weight of a soil colloid – The weight of clay or organic colloid that has a combining power equivalent to 1 gram atomic weight of hydrogen.

erode – To wear away or remove the land surface by wind, water, or other agents.

erodible – Susceptible to erosion. (Expressed by terms such as highly erodible, slightly erodible, etc.)

erosion – (i) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (ii) Detachment and movement of soil or rock by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion:

accelerated erosion – Erosion much more rapid than normal, natural, geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals.

geological erosion – The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of flood plains, coastal plains, etc. Synonymous with natural erosion.

gully erosion – The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 or 2 feet to as much as 75 to 100 feet.

natural erosion – Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Synonymous with geological erosion.

normal erosion – The gradual erosion of land used by man which does not greatly exceed natural erosion. See natural erosion.

rill erosion – An erosion process in which numerous small channels of only several inches in depth are formed; occurs mainly on recently cultivated soils. See rill.

sheet erosion. The removal of a fairly uniform layer of soil from the land surface by runoff water.

splash erosion – The spattering of small soil particles caused by the impact of raindrops on very wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

erosion classes – A grouping of erosion conditions based on the degree of erosion or on characteristic patterns. (Applied to accelerated erosion; not to normal, natural, or geological erosion.) Four erosion classes are recognized for water erosion and three for wind erosion. Specific definitions for each vary somewhat from one climatic zone, or major soil group, to another. (For details see Soil Survey Staff, SCS, USDA. 1951. Soil survey manual. U. S. Dept. Agr. Handbook 18. U. S. Government Printing Office, Washington.)

erosion pavement – A layer of coarse fragments, such as sand or gravel, remaining on the surface of the ground after the removal of fine particles by erosion.

eutrophic – Having concentrations of nutrients optimal (or nearly so) for plant or animal growth. (Said of nutrient solutions or of soil solutions.)

evapotranspiration – The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.

exchange acidity – The titratable hydrogen and aluminum that can be replaced from the adsorption complex by a neural salt solution. Usually expressed as milliequivalents per 100 grams of soil.

exchange capacity – The total ionic charge of the adsorption complex active in the adsorption of ions. See anion-exchange capacity and cation-exchange capacity.

exchangeable-cation percentage – The extent to which the adsorption complex of a soil is occupied by a particular cation. It is expressed as follows:

$$\mathrm{ECP} = \frac{\text{Exchangeable cation (meq/100 g soil)}}{\text{Cation-exchange capacity (meq/100 g soil)}} \times 100.$$

exchangeable phosphate – The phosphate anion reversibly attached to the surface of the solid phase of the soil in such form that it may go into solution by anionic equilibrium reactions with isotopes of phosphorus or with other anions of the liquid phase without solution of the colloid phase to which it was attached.

exchangeable potassium – The potassium that is held by the adsorption complex of the soil and is easily exchanged with the cation of neutral nonpotassium salt solutions.

exchangeable-sodium percentage – The extent to which the adsorption complex of a soil is occupied by sodium. It is expressed as follows:

$$\mathrm{ESP} = \frac{\text{Exchangeable sodium (meq/100 g soil)}}{\text{Cation-exchange capacity (meq/100 g soil)}} \times 100.$$

F

F layer – A layer of partially decomposed litter with portions of plant structures still recognizable. Occurs below the L layer (O11 horizon) on the forest floor in forest soils. It is the fermentation layer or the O12 layer. See L layer and soil horizon.

family, soil – In soil classification one of the categories intermediate between the great soil group and the soil series. See classification, soil.

fertility, soil – The status of a soil with respect to the amount and availability to plants of elements necessary for plant growth.

fertilizer – Any organic or inorganic material of natural or synthetic origin which is added to a soil to supply certain elements essential to the growth of plants.

fertilizer grade – The guaranteed minimum analysis, in per cent, of the major plant nutrient elements contained in a fertilizer material or in a mixed fertilizer. (Usually refers to the percentage of $N\text{-}P_2O_5\text{-}K_2O$ but proposals are pending to change the designation to the percentage of N-P-K.)

fertilizer requirement – The quantity of certain plant nutrient elements needed, in addition to the amount supplied by the soil, to increase plant growth to a designated optimum.

field capacity (field moisture capacity) - (Obsolete in technical work.) The percentage of water remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased. (The percentage may be expressed on the basis of weight or volume.) See moisture tension.

film water – A layer of water surrounding soil particles and varying in thickness from 1 or 2 to perhaps 100 or more molecular layers. Usually considered as that water remaining after drainage has occurred, because it is not distinguishable in saturated soils.

fine sand – (i) A soil separate. See soil separates. (ii) A soil textural class. See soil texture.

fine sandy loam – See soil texture.

fine texture - Consisting of or containing large quantities of the fine fractions, particularly of silt and clay. (Includes all clay loams and clays; that is, clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes. Sometimes subdivided into clayey texture and moderately fine texture.) See soil texture.

fire, ground – (Forestry) A fire that consumes all organic material of the forest floor and also burns into the underlying soil itself, as, for example, a peat fire. Differentiated from a surface fire on the basis of vulnerability to wind; in a surface fire the flames are visible and burning is accelerated by wind, whereas, in a ground fire, wind is generally not a serious factor.

firm – A term describing the consistency of a moist soil that offers distinctly noticeable resistance to crushing but can be crushed with moderate pressure between the thumb and forefinger. See consistency.

first bottom – The normal flood plain of a stream.

fixation – The process or processes in a soil by which certain chemical elements essential for plant growth are converted from a soluble or exchangeable form to a much less soluble or to a nonexchangeable form; for example, phosphate "fixation." Contrast with nitrogen fixation.

fixed phosphorus – (i) That phosphorus which has been changed to a less soluble form as a result of reaction with the soil; moderately available phosphorus. More specifically, that quantity of soluble phosphorus compounds which, when added to soil, becomes chemically or biologically attached to the solid phase of soil so as not to be recovered by extracting the soil with a specified extractant under specified conditions. Such extractants include: water, carbonated water, or dilute solutions of strong mineral acids with or without fluoride or other exchangeable anion. (ii) Applied phosphorus that is not absorbed by plants during the first cropping year. (iii) Soluble phosphorus that has become attached to the solid phase of the soil in forms highly unavailable to crops; unavailable phosphorus; phosphorus in other than readily or moderately available forms.

flaggy – See coarse fragments.

flagstone – A relatively thin fragment, 6 to 15 inches long, of sandstone, limestone, slate, shale or, rarely, of schist. See coarse fragments.

flooding – See irrigation methods.

flood plain – The land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage. See first bottom.

flow velocity (of water in soil) – The volume of water transferred per unit of time and per unit of area normal to the direction of the net flow.

fluvioglacial – See glaciofluvial deposits.

foliar diagnosis – An estimation of the extent to which plants are getting certain necessary chemical elements from the soil by examination of the color and growth habits of the foliage of the plants.

forest floor – All dead vegetable or organic matter, including litter and unincorporated humus, on the mineral soil surface under forest vegetation.

forest soils – (i) Soils developed under forest vegetation. (ii) Soils formed in temperate climates under forest vegetation (European usage).

fragipan – A natural subsurface horizon with high bulk density relative to the solum above, seemingly cemented when dry, but when moist showing a moderate to weak brittleness. The layer is low in organic matter, mottled, slowly or very slowly permeable to water, and usually shows occasional or frequent bleached cracks forming polygons. It may be found in profiles of either cultivated or virgin soils but not in calcareous material.

friable – A consistency term pertaining to the ease of crumbling of soils. See consistency.

frost, concrete – Ice in the soil in such quantity as to constitute a virtually solid block.

frost, honeycomb – Ice in the soil in insufficient quantity to be continuous, thus giving the soil an open, porous structure permitting the ready entrance of water.

fulvic acid – A term of varied usage but usually referring to the mixture of organic substances remaining in solution upon acidification of a dilute alkali extract from the soil.

furrow irrigation – See irrigation methods.

G

genetic – Resulting from, or produced by, soil-forming processes: for example, a genetic soil profile or a genetic horizon.

gilgai – The microrelief of soils produced by expansion and contraction with changes in moisture. Found in soils that contain large amounts of clay which swells and shrinks considerably with wetting and drying. Usually a succession of microbasins and microknolls in nearly level areas or of microvalleys and microridges parallel to the direction of the slope. See microrelief.

glacial drift – Rock debris that has been transported by glaciers and deposited, either directly from the ice or from the meltwater. The debris may or may not be heterogeneous.

glaciofluvial deposits – Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces. See glacial drift and till, (i).

Gleyzation – A soil-forming process resulting in the development of gley soils. See Humic Gley soil and Dark Gray Gleysolic soil.

Gley soil – (Obsolete in the USA) Soil developed under conditions of poor drainage resulting in reduction of iron and other elements and in gray colors and mottles.

glycophytes – Nonhalophytic plants or plants that do not grow well when the osmostic pressure of the soil solution rises above two bars.

grain density – See particle density.

granular structure – See soil structure and soil structure types.

granule – A natural soil aggregate or ped which is relatively nonporous. See soil structure and soil structure types.

gravelly – Containing appreciable or significant amounts of gravel. (Used to describe soils or lands.) See coarse fragments.

gravitational potential – See soil water.

gravitational water – Water which moves into, through, or out of the soil under the influence of gravity.

Gray-Brown Podzolic soil – A zonal great soil group consisting of soils with a thin, moderately dark A1 horizon and with a grayish-brown A2 horizon underlain by a B horizon containing a high percentage of bases and an appreciable quantity of illuviated silicate clay: formed on relatively young land surfaces, mostly glacial deposits, from material relatively rich in calcium, under deciduous forests in humid temperate regions.

Gray Desert soil – A term used in Russia, and frequently in the United States, synonymously with Desert soil. See Desert soil.

Great soil group – One of the categories in the system of soil classification that has been used in the United States for many years. See classification, soil.

green manure – Plant material incorporated with the soil while green, or soon after maturity, for improving the soil.

green-manure crop – A crop grown for use as green manure. See green manure.

groundwater – That portion of the total precipitation which at any particular time is either passing through or standing in the soil and the underlying strata and is free to move under the influence of gravity. See water table.

Ground-Water Laterite soil – A great soil group of the intrazonal order and hydromorphic suborder, consisting of soils characterized by hardpans or concretional horizons rich in iron and aluminum (and sometimes manganese) that have formed immediately above the water table.

Ground-Water Podzol soil – A great soil group of the intrazonal order and hydromorphic suborder, consisting of soils with an organic mat on the surface over a very thin layer of acid humus material underlain by a whitish-gray leached layer, which may be as much as 2 or 3 feet in thickness, and is underlain by a brown, or very dark-brown, cemented hardpan layer; formed under various types of forest vegetation in cool to tropical, humid climates under conditions of poor drainage.

gully – A channel resulting from erosion and caused by the concentrated but intermittent flow of water usually during and immediately following heavy rains. Deep enough to interfere with, and not to be obliterated by, normal tillage operations.

gully erosion – See erosion, (ii).

gyttja – Sedimentary peat consisting mainly of plant and animal residues precipitated from standing water.

H

H layer – A layer occurring in mor humus consisting of well-decomposed organic matter of unrecognizable origin. The O2 horizon. See soil horizon.

Half-Bog soil – A great soil group, of the intrazonal order and hydromorphic suborder consisting of soil with dark-brown or black peaty material over grayish and rust mottled mineral soil; formed under conditions of poor drainage under forest, sedge, or grass vegetation in cool to tropical humid climates.

halomorphic soil – A suborder of the intrazonal soil order, consisting of saline and alkali soils formed under imperfect drainage in arid regions and including the great soil groups Solonchak or Saline soils, solonetz soils, and soloth soils.

halophytic vegetation – Salt-loving or salt-tolerant vegetation, usually having fleshy leaves or thorns and resembling desert vegetation.

hardpan – A hardened soil layer, in the lower A or in the B horizon, caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in moisture content and pieces of the hard layer do not slake in water. See caliche and claypan.

heavy soil – (Obsolete in scientific use.) A soil with a high content of the fine separates, particularly clay, or one with a high drawbar pull and hence difficult to cultivate. See fine texture.

heterotrophic – Capable of deriving energy for life processes only from the decomposition of organic compounds and incapable of using inorganic compounds as sole sources of energy or for organic synthesis. Contrast with autotrophic.

horizon – See soil horizon.

hue – One of the three variables of color. It is caused by light of certain wavelengths and changes with the wavelength. See Munsell color system, chroma, and value, color.

humic acid – A mixture of variable or indefinite composition of dark-colored organic substances, precipitated upon acidification of a dilute-alkali extract from soil. (Used by some workers to designate only the alcohol-soluble portion of this precipitate.) (In chemical literature, it is sometimes used to designate a preparation obtained by the treatment of sugars with mineral acids.)

Humic Gley soil – Soil of the intrazonal order and hydromorphic suborder that includes Wisenboden and related soils, such as Half-Bog soils, which have a thin muck or peat O2 horizon and an A1 horizon. Developed in wet meadow and in forested swamps.

humification – The processes involved in the decomposition of organic matter and leading to the formation of humus.

humin – The fraction of the soil organic matter that is not dissolved upon extraction of the soil with dilute alkali.

humus – (i) That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually it is dark colored. (ii) Includes the F and H Layers in undisturbed forest soils. See soil organic matter, mor, mull, and soil horizon.

hydraulic conductivity – See soil water.

hydraulic gradient – See soil water.

hydraulic head – See soil water.

hydrogenic soil – Soil developed under the influence of water standing within the profile for considerable periods; formed mainly in cold, humid regions.

hydrologic cycle – The fate of water from the time of precipitation until the water has been returned to the atmosphere by evaporation and is again ready to be precipitated.

hydromorphic soils – A suborder of intrazonal soils, consisting of seven great soil groups, all formed under conditions of poor drainage in marshes, swamps, seepage areas, or flats. See classification, soil.

hydrous mica – A silicate clay with 2:1 lattice structure, but of indefinite chemical composition since usually part of the silicon in the silica tetrahedral layer has been replaced by aluminum, and containing a considerable amount of potassium which serves as an additional bonding between the crystal units, resulting in particles larger than normal in montmorillonite and, consequently, in a lower cation-exchange capacity. Sometimes referred to as illite. See clay mineral.

hygroscopic water – Water adsorbed by a dry soil from an atmosphere of high relative humidity, water remaining in the soil after "air-drying," or water held by the soil when it is in equilibrium with an atmosphere of a specified relative humidity at a specified temperature, usually 98% relative humidity at 25C.

hymatomelanic acid – The fraction of humus that is soluble in alcohol, after having been extracted with alkali and precipitated with acid, and which, upon distillation of the alcohol and drying, forms a brittle mass that is insoluble in alcohol. Contains certain tannins and the alcohol-soluble part of humic and ulmic acids.

I

igneous rock – Rock formed from the cooling and solidification of magma, and that has not been changed appreciably since its formation.

illite – A hydrous mica. See hydrous mica.

illuvial horizon – A soil layer or horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension. The layer of accumulation. See eluvial horizon.

illuviation – The process of deposition of soil material removed from one horizon to another in the soil; usually from an upper to a lower horizon in the soil profile. See eluviation.

immature soil – A soil with indistinct or only slightly developed horizons because of the relatively short time it has been subjected to the various soil-forming processes. A soil that has not reached equilibrium with its environment.

immobilization – The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to other organisms or to plants.

impeded drainage – A condition which hinders the movement of water through soils under the influence of gravity.

indicator plants – Plants characteristic of specific soil or site conditions.

infiltration – The downward entry of water into the soil.

infiltration rate – A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water. It has the dimensions of velocity (i.e., $cm^3\ cm^{-2}\ sec^{-1} = cm\ sec^{-1}$). (Formerly, the infiltration capacity.) See infiltration velocity.

infiltration velocity – The actual rate at which water is entering the soil at any given time. It may be less than the maximum (the infiltration rate) because of a limited supply of water (rainfall or irrigation). It has the same units as the infiltration rate. See infiltration rate.

infiltrometer – A device for measuring the rate of entry of fluid into a porous body, e.g., water into soil.

intergrade – A soil that possesses moderately well-developed distinguishing characteristics of two or more genetically related great soil groups.

intrazonal soils – (i) One of the three orders in soil classification. See classification, soil. (ii) A soil with more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief, parent material, or age, over the normal effect of climate and vegetation.

intrinsic permeability – The property of a porous material that relates to the ease with which gases or liquids can pass through it. The Darcy "k" multiplied by $\eta/\rho g$,
where

η is the viscosity of the fluid in poises,
ρ is the density of the fluid in g/cm^3, and
g is the acceleration of gravity in cm/sec^{-2}.

See permeability and soil water.

ions – Atoms, groups of atoms, or compounds, which are electrically charged as a result of the loss of electrons (cations) or the gain of electrons (anions).

ion activity – The effective concentration of a particular ion in a solution or soil-water system. It is expressed analogously to pH, as "pCa," "pNa," etc.

iron-pan – An indurated soil horizon in which iron oxide is the principal cementing agent.

irrigation – The artificial application of water to the soil for the benefit of growing crops.

irrigation efficiency – The ratio of the water actually consumed by crops on an irrigated area to the amount of water diverted from the source onto the area.

irrigation methods – The manner in which water is artificially applied to an area. The methods and the manner of applying the water are as follows:

- **border-strip** – The water is applied at the upper end of a strip with earth borders to confine the water to the strip.
- **check-basin** – The water is applied rapidly to relatively level plots surrounded by levees. The basin is a small check.
- **corrugation** – The water is applied to small, closely-spaced furrows, frequently in grain and forage crops, to confine the flow of irrigation water to one direction.
- **flooding** – The water is released from field ditches and allowed to flood over the land.
- **furrow** – The water is applied to row crops in ditches made by tillage implements.
- **sprinkler** – The water is sprayed over the soil surface through nozzles from a pressure system.
- **subirrigation** – The water is applied in open ditches or tile lines until the water table is raised sufficiently to wet the soil.
- **wild-flooding** – The water is released at high points in the field and distribution is uncontrolled.

isodyne – Points of equal dynamometer pull of a cultivating implement; a line on a map of a cultivated field connecting points of equal dynamometer pull.

isomorphous substitution – The replacement of one atom by another of similar size in a crystal lattice without disrupting or changing the crystal structure of the mineral.

K

kame – An irregular ridge or hill of stratified glacial drift.

kaolin – (i) An aluminosilicate mineral of the 1:1 crystal lattice group; that is, consisting of one silicon tetrahedral layer and one aluminum oxide-hydroxide octahedral layer. (ii) The 1:1 group or family of aluminosilicates.

L

L layer (litter) – The surface layer of the forest floor consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits. This layer may be very thin or absent during the growing season. The O1 horizon. See soil horizon.

lacustrine deposit – Material deposited in lake water and later exposed either by lowering of the water level or by the elevation of the land.

lacustrine soil – (Obsolete) Soil formed on or from lacustrine deposits.

lagg – The depressed margin of a raised bog.

land classification – The arrangement of land units into various categories based upon the properties of the land or its suitability for some particular purpose.

landscape – All the natural features such as fields, hills, forests, water, etc., which distinguish one part of the earth's surface from another part. Usually that portion of land or territory which the eye can comprehend in a single view, including all its natural characteristics.

landslide – (i) A mass of material which has slipped down hill under the influence of gravity, frequently assisted by water (that is, when the material is saturated). (ii) Rapid movement down slope of a mass of soil, rock, or debris.

land type – See soil association.

land, wild – Uncultivated land; it may or may not be maintained by the owner for its productive vegetative cover or for wood, forage production, recreation, or wildlife.

Lateritic soil – A suborder of zonal soils formed in warm, temperate, and tropical regions and including the following great soil groups: Yellow Podzolic, Red Podzolic, Yellowish-Brown Lateritic, and Lateritic. See classification, soil and Latosol.

Latosol – A suborder of zonal soils including soils formed under forested, tropical, humid conditions and characterized by low silica-sesquioxide ratios of the clay fractions, low base-exchange capacity, low activity of the clay, low content of most primary minerals, low content of soluble constituents, a high degree of aggregate stability, and usually having a red color. See classification, soil and Lateritic soil.

lattice energy – The energy required to separate the ions of a crystal to an infinite distance from each other.

lattice structure – The orderly arrangement of atoms in a crystalline material.

Leached Saline soils – (i) Soils from which the soluble salts have been removing by leaching. (ii) Soils that have been saline and still possess the major physical characteristics of saline soils but from which the soluble salts have been leached, generally for reclamation.

leaching – The removal of materials in solution from the soil. See eluviation.

lime, agricultural – A soil amendment consisting principally of calcium carbonate but including magnesium carbonate and perhaps other materials, and used to furnish calcium and magnesium as essential elements for the growth of plants and to neutralize soil acidity.

lime concretion – An aggregate of precipitated calcium carbonate, or of other material cemented by precipitated calcium carbonate.

lime-pan – A hardened layer cemented by calcium carbonate.

lime requirement – The mass of agricultural limestone, or the equivalent of other specified liming material, required per acre to a soil depth of 6 inches (or on 2 million pounds of soil) to raise the pH of the soil to a desired value under field conditions.

liquid limit – The minimum percentage (by weight) of moisture at which a small sample of soil will barely flow under a standard treatment. Synonymous with "upper plastic limit." See plastic limit and plasticity number.

lithosequence – A group of related soils that differ, one from the other, in certain properties primarily as a result of differences in the parent rock as a soil-forming factor.

Lithosols – A great soil group of azonal soils characterized by an incomplete solum or no clearly expressed soil morphology and consisting of freshly and imperfectly weathered rock or rock fragments.

loam – A soil textural class. See soil texture.

loamy – Intermediate in texture and properties between fine-textured and coarse-textured soils. Includes all textural classes with the words "loam" or "loamy" as a part of the class name, such as clay loam or loamy sand. See loam and soil texture.

loess – Material transported and deposited by wind and consisting of predominantly silt-sized particles.

lysimeter – (i) A device for measuring percolation and leaching losses from a column of soil under controlled conditions. (ii) A device for measuring gains (precipitation and condensation) and losses (evapotranspiration) by a column of soil.

M

macronutrient – A chemical element necessary in large amounts (usually >1 ppm in the plant) for the growth of plants and usually applied artificially in fertilizer or liming materials ("macro" refers to quantity and not to the essentiality of the element). See micronutrient.

macroscopic velocity – See flow velocity.

made land – Areas filled with earth, or with earth and trash mixed, usually by or under the control, of man. A miscellaneous land type.

manure – (i) The excreta of animals, with or without the admixture of bedding or litter, in varying stages of decomposition. Also referred to as "barnyard manure" or "stable manure." (The usual meaning of the term as used in the USA; in many other countries "manure" refers to any fertilizer.)

marl – Soft and unconsolidated calcium carbonate, usually mixed with varying amounts of clay or other impurities.

marsh – Periodically wet or continually flooded areas with the surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants. Subclasses include fresh-water and salt-water marshes. See swamp.

mature soil – A soil with well-developed soil horizons produced by the natural processes of soil formation and essentially in equilibrium with its present environment.

maximum water-holding capacity – The average moisture content of a disturbed sample of soil, 1 cm high, which is at equilibrium with a water table at its lower surface.

meander land – Unsurveyed land along a lake shore or stream border that has developed by the receding of the shore line or of the stream since the last cadastral survey of the area. A miscellaneous land type.

mechanical analysis – (Obsolete) See particle-size analysis and particle-size distribution.

medium-texture – Intermediate between fine-textured and coarse-textured (soils) (It includes the following textural classes: very fine sandy loam, loam, silt loam, and silt.)

mellow soil – A very soft, very friable, porous soil without any tendency toward hardness or harshness. See consistency.

mesophilic bacteria – Bacteria whose optimum temperature for growth falls in an intermediate range of approximately 15 to 45C.

metamorphic rock – Rock derived from pre-existing rocks but that differ from them in physical, chemical, and mineralogical properties as a result of natural geological processes, principally heat and pressure, originating within the earth. The pre-existing rocks may have been igneous, sedimentary, or another form of metamorphic rock.

microclimate – (i) The climatic condition of a small area resulting from the modification of the general climatic conditions by local differences in elevation or exposure. (ii) The sequence of atmospheric changes within a very small region.

microfauna – That part of the animal population which consists of individuals too small to be clearly distinguished without the use of a microscope. Includes protozoa and nematodes.

microflora – That part of the plant population which consists of individuals too small to be clearly distinguished without the use of a microscope. Includes actinomycetes, algae, bacteria, and fungi.

micronutrient – A chemical element necessary in only extremely small amounts (< 1 ppm in the plant) for the growth of plants. Examples are: B, Cl, Cu, Fe, Mn, and Zn. ("micro" refers to the amount used rather than to its essentiality.) See macronutrient.

microrelief – Small-scale, local differences in topography, including mounds, swales, or pits that are only a few feet in diameter and with elevation differences of up to 6 feet. See coppice mound, cradle knoll, and gilgai.

mine dumps – Areas covered with overburden and other waste materials from ore and coal mines, quarries, and smelters, and usually with little or no vegetative cover. A miscellaneous land type.

mine wash – Water-deposited accumulations of sandy, silty, or clayey material recently eroded in mining operations. It may clog streams and channels, and damage land on which it is deposited. A miscellaneous land type.

mineralization – The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

mineralogical analysis – The estimation or determination of the kinds or amounts of minerals present in a rock or in a soil.

mineral soil – A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter. Usually contains <20% organic matter, but may contain an organic surface layer up to 30 cm thick.

minor element – (Obsolete) See micronutrient.

miscellaneous land type – A mapping unit for areas of land that have little or no natural soil, that are too nearly inaccessible for orderly examination, or that for any reason it is not feasible to classify the soil. See badland, made land, meander land, mine dumps, mine wash, oil wasteland, river wash, rough broken land, rubble land, scoria land, slickens, stony land, swamp, tidal flats, urban land, volcanic-ash land, and waste land.

moderately-coarse texture – Consisting predominantly of coarse particles. (In soil textural classification, it includes all the sandy loams except the very fine sandy loam.) See coarse texture.

moderately-fine texture – Consisting predominantly of intermediate-size (soil) particles or with relatively small amounts of fine or coarse particles. (In soil textural classification, it includes clay loam, sandy clay loam, and silty clay loam.) See fine texture.

moisture equivalent – The weight percentage of water retained by a previously saturated sample of soil 1 cm in thickness after it has been subjected to a centrifugal force of one thousand times gravity for 30 min.

moisture-release curve – See moisture-retention curve.

moisture-retention curve – A graph showing the soil moisture percentage (by weight or by volume) versus applied tension (or pressure). Points on the graph are usually obtained by increasing (or decreasing) the applied tension or pressure over a specified range.

moisture tension (or pressure) – The equivalent negative pressure in the soil water. It is equal to the equivalent pressure that must be applied to the soil water to bring it to hydraulic equilibrium, through a porous permeable wall or membrane, with a pool of water of the same composition. See soil water. The pressures used and the corresponding percentages most commonly determined are:

fifteen-atmosphere percentage – The percentage of water contained in a soil that has been saturated, subjected to, and is in equilibrium with, an applied pressure of 15 atm. (Pressure applied in a pressure membrane or ceramic pressure plate apparatus. Usually expressed as a weight percentage but may be expressed as a volume percentage. Approximately the same as fifteen-bar percentage.)

fifteen-bar percentage – The percentage of water contained in a soil that has been saturated, subjected to, and is in equilibrium with, an applied pressure of 15 bars. (Pressure applied in a pressure membrane or ceramic pressure plate apparatus. Usually expressed as a weight percentage but may be expressed as a volume percentage. Approximately the same as the fifteen-atmosphere percentage.)

one-third-atmosphere percentage – The percentage of water contained in a soil that has been saturated, subjected to, and is in equilibrium with, an applied pressure of 1/3 atm. (Pressure applied in a ceramic plate apparatus. Usually expressed as a weight percentage, but may be expressed as a volume percentage. Approximately the same as one-third bar percentage. Also, for medium- to coarse-textured soils approximately numerically equal to moisture equivalent.)

one-third bar percentage – The percentage of water contained in a soil that has been saturated, subjected to, and is in equilibrium with, an applied pressure of 1/3 bar. (Pressure applied in a ceramic plate apparatus. Usually expressed as a weight percentage. Approximately the same as one-third atmosphere percentage. Also, for medium- to coarse-textured soils approximately numerically equal to moisture equivalent.)

sixty-centimeter percentage – The percentage of water contained in a soil that has been saturated, subjected to, and is in equilibrium with, an applied pressure (or tension) equivalent to a column of water 60 cm high. (The pressure may be applied in a pressure plate apparatus or, as a tension, on a tension table. May be expressed on a weight or volume basis. Considered by many to approximate the "field-moisture capacity," especially in medium- to coarse-textured soils.)

moisture volume percentage – The ratio of the volume of water in a soil to the total bulk volume of the soil.

moisture weight percentage – The moisture content expressed as a percentage of the oven-dry weight of soil. See dry-weight percentage.

montmorillonite – An aluminosilicate clay mineral with a 2:1 expanding crystal lattice; that is, with two silicon tetrahedral layers enclosing an aluminum octahedral layer. Considerable expansion may be caused along the C axis by water moving between silica layers of contiguous units. See montmorillonite group.

montmorillonite group – Clay minerals with 2:1 crystal lattice structure; that is, two silicon tetrahedral layers enclosing an aluminum octahedral layer. Consists of montmorillonite, beidellite, nontronite, saponite, and others.

mor – A type of forest humus in which the H layer is present and in which there is practically no mixing of surface organic matter with mineral soil; that is, the transition from the H layer to the A1 horizon is abrupt. (Sometimes differentiated into thick mor, thin mor, granular mor, greasy mor, or felty mor.)

mottled zone – A layer that is marked with spots or blotches of different color or shades of color. The pattern of mottling and the size, abundance, and color contrast of the mottles may vary considerably and should be specified in soil description.

mottling – Spots or blotches of different color or shades of color interspersed with the dominant color.

muck – Highly decomposed organic material in which the original plant parts are not recognizable. Contains more mineral matter and is usually darker in color than peat. See muck soil, peat, and peat soil.

muck soil – (i) A soil containing between 20 and 50% of organic matter. (ii) An organic soil in which the organic matter is well decomposed (USA usage).

mulch – (i) Any material such as straw, sawdust, leaves, plastic film, loose soil, etc., that is spread upon the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc. (ii) To apply mulch to the soil surface.

mulch farming – A system of farming in which the organic residues are not plowed into or otherwise mixed with the soil but are left on the surface as a mulch.

mull – A type of forest humus in which the F layer may or may not be present and in which there is no H layer. The A1 horizon consists of an intimate mixture of organic matter and mineral soil with gradual transition between the A1 and the horizon beneath. (Sometimes differentiated into firm mull, sand mull, coarse mull, medium mull, and fine mull.)

Munsell color system – A color designation system that specifies the relative degrees of the three simple variables of color: hue, value, and chroma. For example: 10YR 6/4 is a color (of soil) with a hue = 10YR, value = 6, and chroma = 4. These notations can be translated into several different systems of color names as desired. See chroma, hue, and value, color.

mycorrhiza – The association, usually symbiotic, of fungi with the roots of seed plants. See ectotrophic mycorrhiza and endotrophic mycorrhiza.

N

natural erosion – See erosion, (ii).

neutral soil – A soil in which the surface layer, at least to normal plow depth, is neither acid nor alkaline in reaction. See acid soil, alkaline soil, pH, and reaction, soil.

nitrate reduction – The biochemical reduction of nitrate.

nitrification – The biochemical oxidation of ammonium to nitrate.

nitrogen assimilation – The incorporation of nitrogen into organic cell substances by living organisms.

nitrogen cycle – The sequence of biochemical changes undergone by nitrogen wherein it is used by a living organism, liberated upon the death and decomposition of the organism, and converted to its original state of oxidation.

nitrogen fixation – The conversion of elemental nitrogen (N_2) to organic combinations or to forms readily utilizable in biological processes.

nodule bacteria – See rhizobia.

O

O horizon – See soil horizon.

oil wasteland – Land on which oily wastes have accumulated. Includes slush pits and adjacent areas affected by oil waste. A miscellaneous land type.

one-third atmosphere percentage – See moisture tension (or pressure).

one-third bar percentage – See moisture tension (or pressure).

organic phosphorus – Phosphorus present as a constituent of an organic compound, or a group of organic compounds such as glycerophosphoric acid, inositol phosphoric acid, cytidylic acid, etc.

organic soil – A soil which contains a high percentage (>15 or 20%) of organic matter throughout the solum.

ortstein – An indurated layer in the B horizon of Podzols in which the cementing material consists of illuviated sesquioxides (mostly iron) and organic matter.

osmotic potential – See soil water.

osmotic pressure – See Soil water.

over-dry soil – Soil which has been dried at 105C until it reaches constant weight.

P

pans – Horizons or layers, in soils, that are strongly compacted, indurated, or very high in clay content. See caliche, claypan, fragipan, and hardpan.

pan, genetic – A natural subsurface soil layer of low or very low permeability, with a high concentration of small particles, and differing in certain physical and chemical properties, from the soil immediately above or below the pan. See claypan, fragipan, and hardpan, all of which are genetic pans.

pan, pressure or induced – A subsurface horizon or soil layer having a higher bulk density and a lower total porosity than the soil directly above or below it, as a result of pressure that has been applied by normal tillage operations or by other artificial means. Frequently referred to as plowpan, plowsole, or traffic pan.

parent material – The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

partial sterilization – The elimination of a portion of a population of microorganisms usually by treatment with heat or chemicals. The process is selective, with certain organisms or groups of organisms being destroyed to a greater extent than others.

particle density – The mass per unit volume of the soil particles. In technical work, usually expressed as grams per cubic centimeter. See bulk density, soil.

particle size – The effective diameter of a particle measured by sedimentation, sieving, or micrometric methods.

particle-size analysis – Determination of the various amounts of the different separates in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods.

particle-size distribution – The amounts of the various soil separates in a soil sample, usually expressed as weight percentages.

parts per million (ppm) – Weight units of any given substance per one million equivalent weight units of oven-dry soil; or, in the case of soil solution or other solution, the weight units of solute per million weight units of solution.

peat – Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter accumulated under conditions of excessive moisture.

peat soil – An organic soil containing more than 50% organic matter. Used in the United States to refer to the stage of decomposition of the organic matter, "peat" referring to the slightly decomposed or undecomposed deposits and "muck" to the highly decomposed materials. See peat, muck, and muck soil.

ped – A unit of soil structure such as an aggregate, crumb, prism, block, or granule, formed by natural processes (in contrast with a clod, which is formed artificially).

pedalfer – (Obsolete) A subdivision of a soil order comprising a large group of soils in which sesquioxides increased relative to silica during soil formation.

pedocal – (Obsolete) A subdivision of a soil order comprising a large group of soils in which calcium accumulated during soil formation.

peneplain – A once high, rugged area which has been reduced by erosion to a low, gently rolling surface resembling a plain.

penetrability – The ease with which a probe can be pushed into the soil. (May be expressed in units of distance, speed, force, or work depending on the type of penetrometer used.)

percolation, soil water – The downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

permafrost – (i) Permanently frozen material underlying the solum. (ii) A perennially frozen soil horizon.

permafrost table – The upper boundary of the permafrost [see permafrost, (i)], coincident with the lower limit of seasonal thaw.

permanent charge – The net negative (or positive) charge of clay particles inherent in the crystal lattice of the particle; not affected by changes in pH or by ion-exchange reactions.

permeability, soil – (i) The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question should be designated. (ii) The property of a porous medium itself that relates to the ease with which gases, liquids, or other substances can pass through it. Previously, frequently considered the "k" in Darcy's law. The "K" in intrinsic permeability. See intrinsic permeability, Darcy's law, and soil water.

pF – (Obsolete) The logarithm of the soil moisture tension expressed in centimeters height of a column of water.

pH, hydrolytic – The arithmetical difference between the pH value of a soil as measured on the soil paste and the value obtained on a 1:10 soil-water suspension.

pH, isohydric – The pH value of a soil identical with that of a buffer solution that remains unchanged when mixed with the soil.

pH, soil – The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale.

pH-dependent charge – That portion of the total charge of the soil (clay) particles which is affected by, and varies with, changes in pH.

phase, soil – A subdivision of a soil type or other unit of classification having characteristics that affect the use and management of the soil but which do not vary sufficiently to differentiate it as a separate type. A variation in a property or characteristic such as degree of slope, degree of erosion, content of stones, etc.

photomap – A mosaic map made from aerial photographs with physical and cultural features shown as on a planimetric map. See planisaic and toposaic.

physical properties (of soils) – Those characteristics, processes, or reactions of a soil which are caused by physical forces and which can be described by, or expressed in, physical terms or equations. Sometimes confused with and difficult to separate from chemical properties; hence, the terms "physical-chemical" or "physicochemical." Examples of physical properties are bulk density, water-holding capacity, hydraulic conductivity, porosity, pore-size distribution, etc.

physical weathering – The breakdown of rock and mineral particles into smaller particles by physical forces such as frost action. See weathering.

physiosorption – The process of attachment of nonionic substances such as polar water molecules, acetic acid molecules, or nucleic acids to clays or to other solid-phase surfaces. The attachment of large molecules to clay particles by ionic processes is not physiosorption.

phytogenic soils – (Obsolete) Soils developed under the dominant influence of the natural vegetation, mainly in temperate regions.

phytometer – A plant or plants used to measure the physical factors of the habitat in terms of physiological activities.

phytomorphic soils – (Canada) Well-drained soils of an association which have developed under the dominant influence of the natural vegetation characteristic of a region. The zonal soils of an area.

pitchy – Dense and hard when dry, breaking with smooth, somewhat lustrous conchoidal fracture into sharp-angled fragments. Wet pitchy peat is very plastic and if squeezed in the hand, oozes between the fingers.

planisaic – A photomap in which the planimetric detail is shown by overprints in colors. See photomap and toposaic.

Planosol – A great soil group of the intrazonal order and hydromorphic suborder consisting of soils with eluviated surface horizons underlain by B horizons more strongly eluviated, cemented, or compacted than associated normal soil.

plastic soil – A soil capable of being molded or deformed continuously and permanently, by relatively moderate pressure, into various shapes. See consistency.

plastic limit – The minimum moisture percentage by weight at which a small sample of soil material can be deformed without rupture. Synonymous with "lower plastic limit." See liquid limit and plasticity number.

plasticity constants – See liquid limit, plastic limit, and plasticity number.

plasticity number – The numerical difference between the liquid and the plastic limit or, synonymously, between the lower plastic limit and the upper plastic limit. Sometimes called "plasticity index."

plasticity range – The range of moisture weight percentage within which a small sample of soil exhibits plastic properties.

plate count – A count of the number of colonies formed on a culture medium which has been inoculated with a small amount of soil for the purpose of estimating the number of certain organisms present in the soil sample.

platy – Consisting of soil aggregates that are developed predominately along the horizontal axes; laminated; flaky. See soil structure types.

pocosin – A swamp, usually containing organic soil, and partly or completely enclosed by a sandy rim. The Carolina Bays of the Southeastern United States.

Podzol – A great soil group of the zonal order consisting of soils formed in cool-temperate to temperate, humid climates, under coniferous or mixed coniferous and deciduous forest, and characterized particularly by a highly-leached, whitish-gray (Podzol) A2 horizon.

podzolization – A process of soil formation resulting in the genesis of Podzols and Podzolic soils.

pore-size distribution – The volume of the various sizes of pores in a soil. Expressed as percentages of the bulk volume (soil plus pore space).

pore space – Total space not occupied by soil particles in a bulk volume of soil.

porosity – The volume percentage of the total bulk not occupied by solid particles.

potassium fixation – The process of converting exchangeable or water-soluble potassium to moderately soluble potassium; i.e., to a form not easily exchanged from the adsorption complex with a cation of a neutral salt solution.

potassium-supply power of soils – The capacity of the soil to supply potassium to growing plants from both the exchangeable and the moderately available forms.

Prairie soils – A zonal great soil group consisting of soils formed under temperate to cool-temperate, humid regions under tall grass vegetation. See classification, soil.

precipitation interception – The stopping, interrupting and temporary holding of precipitation in any form by a vegetative canopy or vegetation residue.

pressure membrane – A membrane, permeable to water and only very slightly permeable to gas when wet, through which water can escape from a soil sample in response to a pressure gradient.

primary mineral – A mineral that has not been altered chemically since deposition and crystallization from molten lava. See secondary mineral.

prismatic soil structure – A soil structure type with prismlike aggregates that have a vertical axis much longer than the horizontal axes. See soil structure types.

productivity, soil – The capacity of a soil, in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. The "specified" limitations are necessary since no soil can produce all crops with equal success nor can a single system of management produce the same effect on all soils. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields.

productive soil – A soil in which the chemical, physical, and biological conditions are favorable for the economic production of crops suited to a particular area.

profile, soil – A vertical section of the soil through all its horizons and extending into the parent material.

psammophytes – Plants which prefer or tolerate sand, particularly fine to medium sand, as a habitat.

pure culture – The growth of a single strain of an organism in the absence of any other living species or strain.

R

R horizon – See soil horizon.

rainfall interception – See precipitation interception.

reaction, soil – The degree of acidity or alkalinity of a soil, usually expressed as a pH value. Descriptive terms commonly associated with certain ranges in pH are: extremely acid, <4.5; very strongly acid, 4.5-5.0; strongly acid, 5.1-5.5; moderately acid, 5.6-6.0; slightly acid, 6.1-6.5; neutral, 6.6-7.3; slightly alkaline, 7.4-7.8; moderately alkaline, 7.9-8.4; strongly alkaline, 8.5-9.0; and very strongly alkaline, >9.1.

Red Desert soil – A zonal great soil group consisting of soils formed under warm-temperate to hot, dry regions under desert-type vegetation, mostly shrubs.

red earth – Highly leached, red clayey soils of the humid tropics, usually with very deep profiles that are low in silica and high in sesquioxides.

Red-Yellow Podzolic soils – A combination of the zonal great soil groups, Red Podzolic and Yellow Podzolic, consisting of soils formed under warm-temperate to tropical, humid climates, under deciduous or coniferous forest vegetation and usually, except for a few members of the Yellow Podzolic Group, under conditions of good drainage.

regolith – The unconsolidated mantle of weathered rock and soil material on the earth's surface; loose earth materials above solid rock. (Approximately equivalent to the term "soil" as used by many engineers.)

Regosol – Any soil of the azonal order without definite genetic horizons and developing from or on deep, unconsolidated, soft mineral deposits such as sands, loess, or glacial drift.

Regur – An intrazonal group of dark calcareous soils high in clay, which is mainly montmorillonitic, and formed mainly from rocks low in quartz; occurring extensively on the Deccan Plateau of India.

Rendzina – A great soil group of the intrazonal order and calcimorphic suborder consisting of soils with brown or black friable surface horizons underlain by light gray to pale yellow calcareous material; developed from soft, highly calcareous parent material under grass vegetation or mixed grasses and forest in humid and semiarid climates.

residual material – Unconsolidated and partly weathered mineral materials accumulated by disintegration of consolidated rock in place.

residual shrinkage – The decrease in the bulk volume of soil in addition to that caused by the loss of water.

residual soil – (Obsolete) A soil formed from, or resting on, consolidated rock of the same kind as that from which it was formed, and in the same location. See residual material.

retentivity profile, soil – A graph showing the retaining capacity of a soil as a function of depth. The retaining capacity may be for water, for water at any given tension, for cations, or for any other substances held by soils.

reticulate mottling – A network of streaks of different color; most commonly found in the deeper profiles of Lateritic soils.

reversion – The changing of essential plant nutrient elements from soluble to less soluble forms as a result of interaction with, or reactions in, the soil. Usually restricted to the conversion of monocalcium phosphate to the less soluble dicalcium phosphate.

rhizobia – Bacteria capable of living symbiotically with higher plants, usually legumes, from which they receive their energy, and capable of using atmospheric nitrogen; hence, the term symbiotic nitrogen-fixing bacteria. (Derived from the generic name Rhizobium.)

rhizoplane – The external surface of plant roots. (As used by some, it includes the surface of the adhering soil particles.)

rhizosphere – That portion of the soil directly affected by plant roots.

rill – A small, intermittent water course with steep sides; usually only a few inches deep and, hence, no obstacle to tillage operations.

rill erosion – See erosion, (ii).

river wash – Barren alluvial land, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water. A miscellaneous land type.

rock land – Areas containing frequent rock outcrops and shallow soils. Rock outcrops usually occupy from 25 to 90% of the area. A miscellaneous land type.

rough broken land – Land with very steep topography and numerous intermittent drainage channels but usually covered with vegetation. See miscellaneous land type and badlands.

rubble land – Land areas with 90% or more of the surface covered with stones and boulders. A miscellaneous land type.

runoff – That portion of the precipitation on an area which is discharged from the area through stream channels. That which is lost without entering the soil is called surface runoff and that which enters the soil before reaching the stream is called ground water runoff or seepage flow from ground water. (In soil science "runoff" usually refers to the water lost by surface flow; in geology and hydraulics "runoff" usually includes both surface and subsurface flow.)

S

saline-alkali soil – (i) A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable-sodium percentage is >15, the conductivity of the saturation extract >4 millimhos per centimeter (at 25C), and the pH is usually 8.5 or less in the saturated soil. (ii) A saline-alkali soil has a combination of harmful quantities of salts and either a high alkalinity or high content of exchangeable sodium, or both, so distributed in the profile that the growth of most crop plants is reduced. (Often called saline-sodic soil.)

saline soil – A nonalkali soil containing sufficient soluble salts to impair its productivity. (This name was formerly applied to any soil containing sufficient soluble salts to interfere with plant growth.)

salinization – The process of accumulation of salts in soil.

salt-affected soil – Soil that has been adversely modified for growth of most crop plants by the presence of certain types of exchangeable ions or of soluble salts. (Includes soil having an excess of salts, or an excess of exchangeable sodium, or both.) See saline-alkali soil, saline soil, and sodic soil.

sand – (i) A soil particle between 0.05 and 2.0 mm in diameter. (ii) Any one of five soil separates, namely: very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. See soil separates. (iii) A soil textural class. See soil texture.

sandy – Containing a large amount of sand. (Applied to any one of the soil classes that contains a large percentage of sand.) See class, soil and soil texture.

sandy clay loam – A soil textural class. See class, soil and soil texture.

sandy clay – A soil textural class. See class, soil and soil texture.

sandy loam – A soil textural class. See class, soil and soil texture.

saturate – (i) To fill all the voids between soil particles with a liquid. (ii) To form the most concentrated solution possible under a given set of physical conditions in the presence of an excess of the solute. (iii) To fill to capacity, as the adsorption complex with a cation species; e.g., H-saturated, etc.

scoria land – Areas of slaglike clinkers, burned shale, and fine-grained sandstone; characteristic of burned-out coal beds. Such areas commonly support a sparse cover of grasses, but are of low agricultural value. A miscellaneous land type.

second bottom – The first terrace above the normal flood plain of a stream.

secondary mineral – A mineral resulting from the decomposition of a primary mineral or from the reprecipitation of the products of decomposition of a primary mineral. See primary mineral.

sedimentary rock – A rock formed from materials deposited from suspension or precipitated from solution and usually being more or less consolidated. The principal sedimentary rocks are sandstones, shales, limestones, and conglomerates.

self-mulching soil – A soil in which the surface layer becomes so well aggregated that it does not crust and seal under the impact of rain but instead serves as a surface mulch upon drying.

separate, soil – See soil separate.

series, soil – See soil series.

shaly – (i) Containing a large amount of shale fragments, as a soil. (ii) A soil phase as, for example, shaly phase. See coarse fragments.

shear – Force, as of a tillage implement, acting at right angles to the direction of movement.

sheet erosion – See erosion, (ii).

Sierozem – A zonal great soil group consisting of soils with pale grayish A horizons grading into calcareous material at a depth of 1 foot or less, and formed in temperate to cool, arid climates under a vegetation of desert plants, short grass, and scattered brush.

silica-alumina ratio – The molecules of silicon dioxide (SiO_2) per molecule of aluminum oxide (Al_2O_3) in clay minerals or in soils.

silica-sesquioxide ratio – The molecules of silicon dioxide (SiO_2) per molecule of aluminum oxide (Al_2O_3) plus ferrix oxide (Fe_2O_3) in clay minerals or in soils.

silt – (i) A soil separate consisting of particles between 0.05 and 0.002 mm in equivalent diameter. See soil separates. (ii) A soil textural class. See soil texture.

silting – The deposition of water-borne sediments in stream channels, lakes, reservoirs, or on flood plains, usually resulting from a decrease in the velocity of the water.

silt loam – A soil textural class containing a large amount of silt and small quantities of sand and clay. See soil texture and class, soil.

silty clay – A soil textural class containing a relatively large amount of silt and clay and a small amount of sand. See soil texture and class, soil.

silty clay loam – A soil textural class containing a relatively large amount of silt, a lesser quantity of clay, and a still smaller quantity of sand. See class, soil and soil texture.

site – (i) In ecology, an area described or defined by its biotic, climatic, and soil conditions as related to its capacity to produce vegetation. (ii) An area sufficiently uniform in biotic, climatic, and soil conditions to produce a particular climax vegetation.

site index – (i) A quantitative evaluation of the productivity of a soil for forest growth under the existing or specified environment. (ii) The height in feet of the dominant forest vegetation taken at or calculated to an index age, usually 50 or 100 years.

sixty-centimeter tension – See moisture tension (or pressure).

slaty – Containing a considerable quantity of slate fragments. (Used to modify soil texture class names as, "slaty clay loam," etc.) See coarse fragments.

slickens – Fine-textured materials separated in placer mining and in ore-mill operations; may be detrimental to plant growth unless confined in specially constructed basins. A miscellaneous land type.

slick spots – Small areas in a field that are slick when wet, due to a high content of alkali or of exchangeable sodium.

Slough Podzol – See Depression Podzol.

sodic soil – (i) A soil that contains sufficient sodium to interfere with the growth of most crop plants. (ii) A soil in which the exchangeable-sodium percentage is 15 or more.

soil – (i) The unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of: parent material, climate (including moisture and temperature effects), macro- and microorganisms, and topography, all acting over a period of time and producing a product–soil–that differs from the material from which it is derived in many physical, chemical, biological and morphological properties, and characteristics.

soil air – The soil atmosphere: the gaseous phase of the soil, being that volume not occupied by solid or liquid.

soil alkalinity – The degree or intensity of alkalinity of a soil, expressed by a value >7.0 on the pH scale.

soil association – (i) A group of defined and named taxonomic soil units occurring together in an individual and characteristic pattern over a geographic region, comparable to plant associations in many ways. (Sometimes called "natural land type.") (ii) A mapping unit used on general soil maps, in which two or more defined taxonomic units occurring together in a characteristic pattern are combined because the scale of the map or the purpose for which it is being made does not require delineation of the individual soils.

soil auger – A tool for boring into the soil and withdrawing a small sample for field or laboratory observation. Soil augers may be classified into several types as follows: (i) those with worm-type bits, unenclosed; (ii) those with worm-type bits inclosed in a hollow cylinder; and (iii) those with a hollow cylinder with a cutting edge at the lower end.

soil chemistry – A division of soil science concerned with the chemical constitution, the chemical properties, and the chemical reactions of soils.

soil classification – See classification, soil.

soil complex – A mapping unit used in detailed soil surveys where two or more defined taxonomic units are so intimately intermixed geographically that it is undesirable or impractical, because of the scale being used, to separate them. A more intimate mixing of smaller areas of individual taxonomic units than that described under soil association.

soil conservation – (i) Protection of the soil against physical loss by erosion or against chemical deterioration; that is, excessive loss of fertility by either natural or artificial means. (ii) A combination of all management and land use methods which safeguard the soil against depletion or deterioration by natural or by man-induced factors. (iii) A division of soil science concerned with soil conservation (i) and (ii).

soil creep – See creep.

soil extract – The solution separated from a soil suspension or from a soil by filtration, centrifugation, suction, or pressure. (May or may not be heated prior to separation.)

soil-formation factors – The variable, usually interrelated natural agencies that are active in and responsible for the formation of soil. The factors are usually grouped into five major categories as follows: parent rock, climate, organisms, topography, and time.

soil genesis – (i) The mode of origin of the soil with special reference to the processes or soil-forming factors responsible for the development of the solum, or true soil, from the unconsolidated parent material. (ii) A division of soil science concerned with soil genesis (i).

soil geography – A subspecialization of physical geography concerned with the areal distributions of soil types.

soil horizon – A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, kinds and numbers of organisms present, degree of acidity or alkalinity, etc. The following table lists the designations and properties of the major soil horizons. Very few if any soils have all of these horizons well developed but every soil has some of them.

Horizon designation	Description
O	Organic horizons of mineral soils. Horizons:(i) formed or forming in the upper part of mineral soils above the mineral part; (ii) dominated by fresh or partly decomposed organic material; and (iii) containing >30% organic matter if the mineral fraction is >50% clay, or >20% organic matter if the mineral fraction has no clay. Intermediate clay content requires proportional organic matter content.
O1	Organic horizons in which essentially the original form of most vegetative matter is visible to the naked eye. The O1 corresponds to the L (litter) and some F (fermentation) layers in forest soils designations, and to the horizon formerly called Aoo.
O2	Organic horizons in which the original form of most plant or animal matter cannot be recognized with the naked eye. The O2 corresponds to the H (humus) and some F (fermentation) layers in forest soils designations, and to the horizon formerly called Ao.
A	Mineral horizons consisting of: (i) horizons of organic-matter accumulation formed or forming at or adjacent to the surface; (ii) horizons that have lost clay, iron, or aluminum with resultant concentration of quartz or other resistant minerals of sand or silt size; or (iii) horizons dominated by (i) or (ii) above but transitional to an underlying B or C.
A1	Mineral horizons, formed or forming at or adjacent to the surface, in which the feature emphasized is an accumulation of humified organic matter intimately associated with the mineral fraction.
A2	Mineral horizons in which the feature emphasized is loss of clay, iron, or aluminum, with resultant concentration of quartz or other resistant minerals in sand and silt sizes.
A3	A transitional horizon between A and B, and dominated by properties characteristic of an overlying A1 or A2 but having some subordinate properties of an underlying B.
AB	A horizon transitional between A and B, having an upper part dominated by properties of A and a lower part dominated by properties of B, and the two parts cannot be conveniently separated into A3 and B1.
A & B	Horizons that would qualify for A2 except for included parts constituting <50% of the volume that would qualify as B.
AC	A horizon transitional between A and C, having subordinate properties of both A and C, but not dominated by properties characteristic of either A or C.
B & A	Any horizon qualifying as B in >50% of its volume including parts that qualify as A2.

Horizon designation	Description
B	Horizons in which the dominant feature or features is one or more of the following: (i) an illuvial concentration of silicate clay, iron, aluminum, or humus, alone or in combination; (ii) a residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts; (iii) coatings of sesquioxides adequate to give conspicuously darker, stronger, or redder colors than overlying and underlying horizons in the same sequum but without apparent illuviation of iron and not genetically related to B horizons that meet requirements of (i) or (ii) in the same sequum; or (iv) an alteration of material from its original conditon in sequums lacking conditions defined in (i), (ii), and (iii) that obliterates original rock structure, that forms silicate clays, liberates oxides, or both, and that forms granular, blocky, or prismatic structure if textures are such that volume changes accompany changes in moisture.
B1	A transitional horizon between B and A1 or between B and A2 in which the horizon is dominated by properties of an underlying B2 but has some subordinate properties of an overlying A1 or A2.
B2	That part of the B horizon where the properties on which the B is based are without clearly expressed subordinate characteristics indicating that the horizon is transitional to an adjacent overlying A or an adjacent underlying C or R.
B3	A transitional horizon between B and C or R in which the properties diagnostic of an overlying B2 are clearly expressed but are associated with clearly expressed properties characteristic of C or R.
C	A mineral horizon or layer, excluding bedrock, that is either like or unlike the material from which the solum is presumed to have formed, relatively little affected by pedogenic processes, and lacking properties diagnostic of A or B but including materials modified by: (i) weathering outside the zone of major biological activity; (ii) reversible cementation, development of brittleness, development of high bulk density, and other properties characteristic of fragipans; (iii) gleying; (iv) accumulation of calcium or magnesium carbonate or more soluble salts; (v) cementation by accumulations such as calcium or magnesium carbonate or more soluble salts; or (vi) cementation by alkali-soluble siliceous material or by iron and silica.
R	Underlying consolidated bedrock, such as granite, sandstone, or limestone. If presumed to be like the parent rock from which the adjacent overlying layer or horizon was formed, the symbol R is used alone. If presumed to be unlike the overlying material, the R is preceded by a Roman numeral denoting lithologic discontinuity.

soil improvement – The process for, or the results of, making the soil more productive for growing plants, by drainage, irrigation, addition of fertilizers and soil amendments, and the like.

soil management – (i) The sum total of all tillage operations, cropping practices, fertilizer, lime, and other treatments conducted on or applied to a soil for the production of plants. (ii) A division of soil science concerned with the items listed under (i).

soil management groups – Groups of taxonomic soil units with similar adaptations or management requirements for one or more specific purposes, such as: adapted crops or crop rotations, drainage practices, fertilization, forestry, highway engineering, etc.

soil map – A map showing the distribution of soil types or other soil mapping units in relation to the prominent physical and cultural features of the earth's surface. The following kinds of soil maps are recognized in the United States:

soil map, detailed – A soil map on which the boundaries are shown between all soil types that are significant to potential use as field-management systems. The scale of the map will depend upon the purpose to be served, the intensity of land use, the pattern of soils, and the scale of the other cartographic materials available. Traverses are usually made at 1/4-mile, or more frequent, intervals. Commonly a scale of 4 inches=1 mile (1:15,840) is now used for field mapping in the U. S.

soil map, detailed reconnaissance – A reconnaissance map on which some areas or features are shown in greater detail than usual, or than others.

soil map, generalized – A small-scale soil map which shows the general distribution of soils within a large area and thus in less detail than on a detailed soil map. Generalized soil maps may vary from soil association maps of a county, on a scale of 1 inch=1 mile (1:63,360), to maps of larger regions showing associations dominated by one or more great soil groups.

soil map, reconnaissance – A map showing the distribution of soils over a large area as determined by traversing the area at intervals varying from about 1/2 mile to several miles. The units shown are soil associations. Such a map is usually made only for exploratory purposes to outline areas of soil suitable for more intensive development. The scale is usually much smaller than for detailed soil maps.

soil map, schematic – A soil map compiled from scant knowledge of the soils of new and undeveloped regions by the application of available information about the soil-formation factors of the area. Usually on a small scale (1:1,000,000 or smaller).

See soil-formation factors.

soil mechanics and engineering – A subspecialization of soil science concerned with the effect of forces on the soil and the application of engineering principles to problems involving the soil.

soil microbiology – A subspecialization of soil science concerned with soil-inhabiting microorganisms and with their relation to agriculture, including both plant and animal growth.

soil mineral – (i) Any mineral that occurs as a part of or in the soil. (ii) A natural inorganic compound with definite physical, chemical, and crystalline properties (within the limits of isomorphism), that occurs in the soil. See clay mineral.

soil mineralogy – A subspecialization of soil science concerned with the homogeneous inorganic materials found in the earth's crust to the depth of weathering or of sedimentation.

soil moisture – Water contained in the soil.

soil-moisture tension – See moisture tension (or pressure).

soil monolith – A vertical section of a soil profile removed from the soil and mounted for display or study.

soil morphology – (i) The physical constitution, particularly the structural properties, of a soil profile as exhibited by the kinds, thickness, and arrangement of the horizons in the profile, and by the texture, structure, consistency, and porosity of each horizon. (ii) The structural characteristics of the soil or any of its parts.

soil organic matter – The organic fraction of the soil; includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Usually determined on soils which have been sieved through a 2.0-mm sieve.

soil piping or tunneling – Accelerated erosion which results in subterranean voids and tunnels.

soil population – All the organisms living in the soil, including plants and animals.

soil pores – That part of the bulk volume of soil not occupied by soil particles; interstices; voids.

soil porosity – See porosity

soil province – (Obsolete) Areas similar in mode of origin of the soil parent materials or in geological or geographic features.

soil reaction – See reaction, soil and pH, soil.

soil salinity – The amount of soluble salts in a soil, expressed in terms of percentage, parts per million, or other convenient ratios.

soil science – That science dealing with soils as a natural resource on the surface of the earth including soil formation, classification and mapping, and the physical, chemical, biological, and fertility properties of soils per se; and these properties in relation to their management for crop production.

soil separates – Mineral particles, <2.0 mm in equivalent diameter, ranging between specified size limits. The names and size limits of separate recognized in the United States are: very coarse sand, [1]2.0 to 1.0 mm; coarse sand, 1.0 to 0.5 mm; medium sand, 0.5 to 0.25 mm; fine sand, 0.25 to 0.10 mm; very fine sand, 0.10 to 0.05 mm; silt, 0.05 to 0.002 mm; and clay,[2] <0.002 mm.

The separates recognized by the International Society of Soil Science are: I) coarse sand, 2.0 to 0.2 mm; II) fine sand, 0.2 to 0.02 mm; III) silt, 0.02 to 0.002 mm; and IV) clay, <0.002 mm.

soil series – The basic unit of soil classification being a subdivision of a family and consisting of soils which are essentially alike in all major profile characteristics except the texture of the A horizon.

soil solution – The aqueous liquid phase of the soil and its solutes consisting of ions dissociated from the surfaces of the soil particles and of other soluble materials.

soil structure – The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively. See soil structure classes, soil structure grades, and soil structure types. Also see Table 1.

soil structure classes – A grouping of soil structural units or peds on the basis of size. See soil structure, soil structure types, and Table 1.

soil structure grades – A grouping or classification of soil structure on the basis of inter- and intra-aggregate adhesion, cohesion, or stability within the profile. Four grades of structure designated from 0 to 3 are recognized as follows:

0) Structureless – no observable aggregation or no definite and orderly arrangement of natural lines of weakness. Massive, if coherent; single-grain, if noncoherent.

1) Weak – poorly formed indistinct peds, barely observable in place.

2) Moderate – well-formed distinct peds, moderately durable and evident, but not distinct in undisturbed soil.

3) Strong – durable peds that are quite evident in undisturbed soil, adhere weakly to one another, withstand displacement, and become separated when the soil is disturbed.

soil structure types – A classification of soil structure based on the shape of the aggregates or peds and their arrangement in the profile. See soil structure, soil structure classes, soil structure grades, and Table 1.

soil survey – The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination.

soil texture – The relative proportions of the various soil separates in a soil as described by the classes of soil texture shown in Fig. 1. The textural classes may be modified by the addition of suitable adjectives when

Table 1 – Types and classes of soil structure*

	Type (shape and arrangement of peds)						
Class	Platelike with one dimension (the vertical) limited and greatly less than the other two; arranged around a horizontal plane; faces mostly horizontal	Prismlike with two dimensions (the horizontal) limited and considerably less than the vertical; arranged around a vertical line; vertical faces well defined; vertices angular		Blocklike; polyhedronlike, or spheroidal, with three dimensions of the same order of magnitude, arranged around a point			
				Blocklike; blocks or polyhedrons having plane or curved surfaces that are casts of the molds formed by the faces of the surrounding peds		Spheroids of polyhedrons having plane or curved surfaces which have slight or no accommodation to the faces of surrounding peds	
		Without rounded caps	With rounded caps	Faces flattened; most vertices sharply angular	Mixed rounded and flattened faces with many rounded vertices	Relatively nonporous peds	Porous peds
	Platy	Prismatic	Columnar	(Angular) Blocky†	Subangular blocky ‡	Granular	Crumb
Very fine or very thin	Very thin platy; <1 mm	Very fine prismatic; <10 mm	Very fine columnar; <10 mm	Very fine angular blocky; <5 mm	Very fine subangular blocky; <5 mm	Very fine granular; <1 mm	Very fine crumb; <1 mm
Fine or thin	Thin platy; <1 - 2 mm	Fine prismatic; 10 - 20 mm	Fine columnar; 10 - 20 mm	Fine angular blocky; 5 - 10 mm	Fine subangular blocky; 5 - 10 mm	Fine granular; 1 - 2 mm	Fine crumb; 1 - 2 mm
Medium	Medium platy; <2 - 5 mm	Medium prismatic; 20 - 50 mm	Medium columnar; 20 - 50 mm	Medium angular blocky; 10 - 20 mm	Medium subangular blocky; 10 - 20 mm	Medium granular; 2 - 5 mm	Medium crumb; 2 - 5 mm
Coarse or thick	Thick platy; <5 - 10 mm	Coarse prismatic; 50 - 100 mm	Coarse columnar; 50 - 100 mm	Coarse angular blocky; 20 - 50 mm	Coarse subangular blocky; 20 - 50 mm	Coarse granular; 5 - 10 mm	
Very coarse or very thick	Very thick platy; >10 mm	Very coarse prismatic; >100 mm	Very coarse columnar; >100 mm	Very coarse angular blocky; >50 mm	Very coarse subangular blocky; >50 mm	Very coarse granular; >10 mm	

* From: Soil Survey Staff, SCS, USDA, 1951, Soil survey manual. U. S. Dept. Agr. Handbook 18, p. 228, U. S. Government Printing Office, Washington.

† (a) Sometimes called nut. (b) The word "angular" in the name ordinarily can be omitted.

‡ Sometimes called nuciform, nut, or subangular nut. Since the size connotation of these terms is a source of great confusion to many, they are not recommended.

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[1] Prior to 1947 this separate was called "fine gravel;" now fine gravel includes particles between 2.0 mm and about 12.5 mm in diameter.

[2] Prior to 1937, "clay" included particles 0.005 mm in diameter, and "silt," those particles from 0.05 to 0.005 mm.

soil water[3] – (Cont)

total pressure – The pressure (positive or negative), relative to the external gas pressure on the soil water, to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable membrane with the soil water. Total pressure is thus equal to the sum of soil water pressure and osmotic pressure. Total pressure may also be derived from the measurement of the partial pressure of the water vapor in equilibrium with the soil water. May be identified with the total potential defined above when gravitational and external gas pressure potentials can be neglected.

hydraulic head – The elevation with respect to a specified reference level at which water stands in a piezometer connected to the point in question in the soil. Its definition can be extended to soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head in systems under atmospheric pressure may be identified with a potential expressed in terms of the height of a water column. More specifically it can be identified with the sum of gravitational and capillary potentials, and may be termed the hydraulic potential.

water content – The amount of water lost from the soil upon drying to constant weight at 105C; expressed either as the weight of water per unit weight of dry soil or as the volume of water per unit bulk volume of soil. The relationships between water content and soil water pressure can be referred to as the soil moisture characteristic curve. Depending upon whether the curve is determined with decreasing or increasing water content one may designate it as a desorption and adsorption curve, respectively.

differential water capacity – The absolute value of the rate of change of water content with soil water pressure. The water capacity at a given water content will depend on the particular desorption or adsorption curve employed. Distinction should be made between volumetric and specific water capacity.

B. TERMS RELATING TO THE MOVEMENT OF WATER IN SOIL

Experimentally it has been established that generally the flow of a fluid in a porous medium can be described by Darcy's law which states that the flux of fluid is proportional to the driving force. In viscous flow of water in soils, the driving force equals the negative gradient of the hydraulic potential.

hydraulic conductivity – The proportionality factor in Darcy's law as applied to the viscous flow of water in soil, i.e., the flux of water per unit gradient of hydraulic potential. If conditions require that the viscosity of the fluid be divorced from the conductivity of the medium, it is convenient to define the permeability (intrinsic permeability has been used in some publications) of the soil as the conductivity, expressed in $g^{-1}cm^3$ sec multiplied by the viscosity in poise. For the purpose of solving the partial differential equation of the non-steady-state flow in unsaturated soil it is often convenient to introduce a variable termed the soil water diffusivity.

soil water diffusivity – The hydraulic conductivity divided by the differential water capacity (care being taken to be consistent with units), or the flux of water per unit gradient of moisture content in the absence of other force fields.

C. SYMBOL, DIMENSION, AND UNIT FOR THE ABOVE GIVEN TERMS WHEN ONE GRAM MASS IS USED AS UNIT QUANTITY OF WATER

Term	Symbol*	Dimension	Unit
Total potential	Ψ	$L^2 T^{-2}$	erg g^{-1}, joule kg^{-1}
Osmotic potential	O	$L^2 T^{-2}$	erg g^{-1}, joule kg^{-1}
Gravitational potential	Z	$L^2 T^{-2}$	erg g^{-1}, joule kg^{-1}
Capillary potential	M	$L^2 T^{-2}$	erg g^{-1}, joule kg^{-1}
Soil water pressure		$ML^{-1}T^{-2}$	dyne cm^{-2}, bar, cm water, cm Hg
Osmotic pressure		$ML^{-1}T^{-2}$	dyne cm^{-2}, bar, cm water, cm Hg
Total pressure		$ML^{-1}T^{-2}$	dyne cm^{-2}, bar, cm water, cm Hg
Hydraulic head	H	L	cm, m
Hydraulic potential	Φ	$L^2 T^{-2}$	erg g^{-1}, joule kg^{-1}
Water content	w		$cm^3 cm^{-3}$, g g^{-1}
Differential water capacity	C	$M^{-1} LT^2$	cm^2 $dyne^{-1}$, bar^{-1}
Hydraulic conductivity	K		
Permeability	k	L^2	cm^2, Darcy
Soil water diffusivity	D	$L^2 T^{-1}$	cm^2 sec^{-1}

* Symbols as C, K, and D may have w or h as a subscript if they in the same paper are used for water as well as for heat.† The dimension would depend on the units used to describe the driving force as shown in the table below:

Driving force	Dimension	Hydraulic conductivity	
		Dimension	Unit
Hydraulic potential gradient	LT^{-2}	T	sec
Hydraulic head gradient	LL^{-1}	LT^{-1}	cm sec^{-1}
Pressure gradient	$ML^{-2}T^{-2}$	$M^{-1}L^3T$	g^{-1} cm^3 sec

soil water pressure – See soil water.

solclime – The temperature and moisture conditions of the soil: the soil climate.

solodized soil – A soil that has been subjected to the processes responsible for the development of a Soloth and having at least some of the characteristics of a Soloth.

Solonchak – A great soil group of the intrazonal order and halomorphic suborder, consisting of soils with gray, thin, salty crust on the surface, and with fine granular mulch immediately below being underlain with grayish, friable, salty soil; formed under subhumid to arid, hot or cool climate, under conditions of poor drainage and under a sparse growth of halophytic grasses, shrubs, and some trees.

Solonetz – A great soil group of the intrazonal order and halomorphic suborder, consisting of soils with a very thin, friable, surface soil underlain by a dark, hard columnar layer usually highly alkaline; formed under subhumid to arid, hot to cool climates, under better drainage than Solonchaks, and under a native vegetation of halophytic plants.

soluble-sodium percentage (SSP) – The proportion of sodium ions in solution in relation to the total cation concentration, defined as follows:

$$SSP = \frac{\text{Soluble-sodium concentration (meq liter)}}{\text{Total cation concentration (meq liter)}} \text{ X } 100.$$

solum (plural: sola) – The upper and most weathered part of the soil profile; the A and B horizons.

splash erosion – See erosion, (ii).

spoil bank – Rock waste, banks, and dumps, from the excavation of ditches.

sprinkler irrigation – See irrigation methods.

sticky point – (i) A condition of consistency at which the soil barely fails to stick to a foreign object. (ii) Specifically and numerically, the weight moisture percentage of a well-mixed, kneaded soil that barely fails to adhere to a polished nickel or stainless steel surface when the shearing speed is 5 cm/sec.

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[3] The above terms and their definitions relating to soil water are essentially those recommended by a committee of the International Society of Soil Science and published in Bulletin 23 (1963 p. 7-10) of that society. Some editorial changes have been made following comments received from a number of soil physicists in response to an inquiry by the SSSA Committee on Terminology. Because of the strong divergence of opinion expressed by the respondents, the Terminology Committee is listing the terms without approval or disapproval, but with the recommendation that society members express their opinion to the Editor-in-Chief or to the next committee chairman.

Stokes' law – An equation relating the terminal settling velocity of a smooth, rigid sphere in a viscous fluid of known density and viscosity to the diameter of the sphere when subjected to a known force field. Used in particle-size analysis of soils by the pipette, hydrometer, or centrifuge methods. The equation is

$$V = \frac{2gr^2(d_1 - d_2)}{9\eta}$$

where
V = velocity of fall (cm sec^{-1}),
g = acceleration of gravity (cm sec^{-3}),
r = "equivalent" radius of particle (cm),
d_1 = density of particle (g cm^{-3}),
d_2 = density of medium (g cm^{-3}), and
η = viscosity of medium (dyne sec cm^{-2}).

stones – Rock fragments >10 inches in diameter if rounded, and >15 inches along the greater axis if flat. See coarse fragments.

stoniness – The relative proportion of stones in or on the soil. Used in classification of soils. See coarse fragments.

stony – Containing sufficient stones to interfere with or to prevent tillage. To be classified as stony, >0.01% of the surface of the soil must be covered with stones. Used to modify soil class, as stony clay loam or clay loam, stony phase. See coarse fragments.

stony land – Areas containing sufficient stones to make the use of machinery impractical; usually 15 to 90% of the surface is covered with stones. A miscellaneous land type. See stoniness and rubble land.

stratified – Arranged in or composed of strata or layers.

strip cropping – The practice of growing crops which require different types of tillage, such as row and sod, in alternate strips along contours or across the prevailing direction of wind.

structure, soil – See soil structure.

structure index – Any measurement of a soil physical property, such as aggregation, porosity, permeability to air or water, or bulk density, that denotes or indicates the structural condition of a soil.

stubble mulch – The stubble of crops or crop residues left essentially in place on the land as a surface cover before and during the preparation of the seedbed and at least partly during the growing of a succeeding crop.

Subarctic Brown Forest soils – Soils similar to Brown Forest soils except having more shallow sola and average temperatures of <5C at 18 inches or more below the surface.

subirrigation – See irrigation methods.

subsoiling – Breaking of compact subsoils, without inverting them, with a special knife-like instrument (chisel) which is pulled through the soil at depths usually of 12 to 24 inches and at spacings usually of 2 to 5 feet.

substrate – (i) That which is laid or spread under; an underlying layer, such as the subsoil. (ii) The substance, base, or nutrient on which an organism grows. (iii) Compounds or substances that are acted upon by enzymes or catalysts and changed to other compounds in the chemical reaction.

subsurface tillage – Tillage with a special sweeplike plow or blade which is drawn beneath the surface at depths of several inches and cuts plant roots and loosens the soil without inverting it or without incorporating the surface cover.

Sulfofication – (Obsolete) The biological oxidation of sulfur and sulfur compounds in the soil.

summation curve, particle size – A curve showing the accumulative percentage by weight of particles within increasing (or decreasing) size limits as a function of diameter; the percent by weight of each size fraction is plotted accumulatively on the ordinate as a function of the total range of diameters represented in the sample plotted on the abscissa.

surface runoff – See runoff.

surface sealing – The orientation and packing of dispersed soil particles in the immediate surface layer of the soil, rendering it relatively impermeable to water.

surface soil – The uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils and ranging in depth from 3 to 4 inches to 8 or 10 inches. Frequently designated as the "plow layer," the "Ap layer," or the "Ap horizon."

swamp – An area saturated with water throughout much of the year but with the surface of the soil usually not deeply submerged. Usually characterized by tree or shrub vegetation. See marsh and miscellaneous land type.

symbiosis – The living together in intimate association of two dissimilar organisms, the cohabitation being mutually beneficial.

symmetry concentration – That quantity of cations (or anions) equivalent to the exchange capacity of a soil. For example, if the cation-exchange capacity of a soil is 10 meq/100 g of soil, then 1 symmetry concentration is 10 meq of any cation.

symmetry value – The percentage of the adsorbed ion released when one symmetry concentration of another ion is added.

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talus – Fragments of rock and other soil material accumulated by gravity at the foot of cliffs or steep slopes.

talud – A short, steep slope formed gradually at the downslope margin of a field by deposition against a hedge, a stone wall, or other similar barrier.

tensiometer – A device for measuring the negative pressure (or tension) of water in soil in situ; a porous, permeable ceramic cup connected through a tube to a manometer or vacuum gauge.

terrace – (i) A level, usually narrow, plain bordering a river, lake, or the sea. Rivers sometimes are bordered by terraces at different levels. (ii) A raised, more or less level or horizontal strip of earth usually constructed on or nearly on a contour and supported on the downslope side by rocks or other similar barrier and designed to make the land suitable for tillage and to prevent accelerated erosion. For example, the ancient terraces built by the Incas in the Andes. (iii) An embankment with the uphill side sloping toward and into a channel for conducting water, and the downhill side having a relatively sharp decline; constructed across the direction of the slope for the purpose of conducting water from the area above the terrace at a regulated rate of flow and to prevent the accumulation of large volumes of water on the downslope side of cultivated fields. The depth of the channel, the width of the terrace ridge, and the spacings of the terraces on a field are varied with soil types, cropping systems, climatic conditions, and other factors.

texture – See soil texture.

textural classification – See soil texture.

thermal analysis (differential thermal analysis) – A method of analyzing a soil sample for constituents, based on a differential rate of heating of the unknown and standard samples when a uniform source of heat is applied.

thermogenic soils – Soils with properties that have been influenced primarily by high temperature as the dominant soil-formation factor; developed in subtropical and equatorial regions.

thermophilic organisms – Organisms which grow readily at temperatures above 45C.

thermosequence – A sequence of related soils that differ, one from the other, primarily as a result of temperature as a soil-formation factor.

threshold moisture content – (Biology) The minimum moisture condition, measured either in terms of moisture content or moisture stress, at which biological activity just becomes measurable.

tidal flats – Areas of nearly flat, barren mud periodically covered by tidal waters. Normally these materials have an excess of soluble salt. A miscellaneous land type.

tight soil – A compact, relatively impervious and tenacious soil (or subsoil) which may or may not be plastic.

tile drain – Concrete or ceramic pipe placed at suitable depths and spacings in the soil or subsoil to provide water outlets from the soil.

till – (i) Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion. (ii) To plow and prepare for seeding; to seed or cultivate the soil.

tilth – The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.

coarse fragments are present in substantial amounts; for example, "stony silt loam," or "silt loam, stony phase." (For other modifications see coarse fragments.) The sand, loamy sand, and sandy loam are further subdivided on the basis of the proportions of the various sand separates present. The limits of the various classes and subclasses are as follows:

sand – Soil material that contains 85% or more of sand; percentage of silt, plus 1.5 times the percentage of clay, shall not exceed 15.

coarse sand – 25% or more very coarse and coarse sand, and <50% any other one grade of sand.

sand – 25% or more very coarse, coarse, and medium sand, and <50% fine or very fine sand.

fine sand – 50% or more fine sand (or) <25% very coarse, coarse, and medium sand and <50% very fine sand.

very fine sand – 50% or more very fine sand.

loamy sand – Soil material that contains at the upper limit 85 to 90% sand, and the percentage of silt plus 1.5 times the percentage of clay is not less than 15; at the lower limit it contains not less than 70 to 85% sand, and the percentage of silt plus twice the percentage of clay does not exceed 30.

loamy coarse sand – 25% or more very coarse and coarse sand, and <50% any other one grade of sand.

loamy sand – 25% or more very coarse, coarse, and medium sand, and <50% fine or very fine sand.

loamy fine sand – 50% or more fine sand (or) <25% very coarse, coarse, and medium sand and <50% very fine sand.

loamy very fine sand – 50% or more very fine sand.

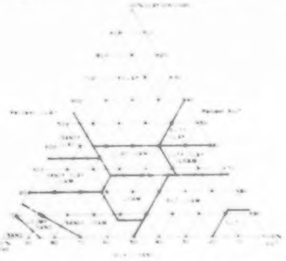

Figure 1 – Graph showing the percentages of sand, silt, and clay in the soil classes.

sandy loam – Soil material that contains either 20% clay or less, and the percentage of silt plus twice the percentage of clay exceeds 30, and 52% or more sand; or <7% clay, <50% silt, and between 43% and 52% sand.

coarse sandy loam – 25% or more very coarse and coarse sand and <50% any other one grade of sand.

sandy loam – 30% or more very coarse, coarse, and medium sand, but <25% very coarse sand, and <30% very fine or fine sand.

fine sandy loam – 30% or more fine sand and <30% very fine sand (or) between 15 and 30% very coarse, coarse, and medium sand.

very fine sandy loam – 30% or more very fine (or) >40% fine and very fine sand, at least half of which is very fine sand and <15% very coarse, coarse, and medium sand.

loam – Soil material that contains 7 to 27% clay, 28 to 50% silt, and <52% sand.

silt loam – Soil material that contains 50% or more silt and 12 to 27% clay (or) 50 to 80% silt and 12% clay.

silt – Soil material that contains 80% or more silt and <12% clay.

sandy clay loam – Soil material that contains 20 to 35% clay, <28% silt, and 45% or more sand.

clay loam – Soil material that contains 27 to 40% clay and 20 to 45% sand.

silty clay loam – Soil material that contains 27 to 40% clay and <20% sand.

sandy clay – Soil material that contains 35% or more clay and 45% or more sand.

silty clay – Soil material that contains 40% or more clay and 40% or more silt.

clay – Soil material that contains 40% or more clay, <45% sand, and <40% silt.

soil type – (i) The lowest unit in the natural system of soil classification; a subdivision of a soil series and consisting of or describing soils that are alike in all characteristics including the texture of the A horizon. (ii) In Europe, roughly equivalent to a great soil group.

soil variant – A soil whose properties are believed to be sufficiently different from other known soils to justify a new series name but comprising such a limited geographic area that creation of a new series is not justified.

soil water[3] –

A. TERMS RELATING TO THE STATE OF WATER IN SOIL

Water in soil is subject to several force fields originating from: the presence of the soil solid phase; the dissolved salts; the action of external gas pressure; and, the gravitational field. These effects may be quantitatively expressed by assigning an individual component potential to each. The sum of these potentials is designated the total potential of soil water and may be identified with the partial specific Gibb's free energy of the soil water relative to free pure water at the same temperature. It should be noted that soil water is understood to be the equilibrium solution in the soil; pure water refers to the chemically pure compound H_2O.

total potential (of soil water) – The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water, at a specified elevation and at atmospheric pressure, to the soil water (at the point under consideration). The total potential (of soil water) consists of the following:

osmotic potential – The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water, at a specified elevation and at atmospheric pressure, to a pool of water identical in composition to the soil water (at the point under consideration), but in all other respects being identical to the reference pool.

gravitational potential – The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water, identical in composition to the soil water, from a pool at a specified elevation and at atmospheric pressure, to a similar pool at the elevation of the point under consideration.

capillary potential – The amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermally an infinitesimal quantity of water, identical in composition to the soil water, from a pool at the elevation and the external gas pressure of the point under consideration, to the soil water.

gas pressure potential – This potential component is to be considered only when external gas pressure differs from atmospheric pressure as, e.g., in a pressure membrane apparatus. A specific term and definition is not given.

soil water pressure – The pressure (positive or negative), relative to the external gas pressure on the soil water, to which a solution identical in composition to the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water. May be identified with the capillary potential defined above.

osmotic pressure – The pressure to which a pool of water, identical in composition to the soil water, must be subjected in order to be in equilibrium, through a semipermeable membrane, with a pool of pure water (semipermeable means permeable only to water). May be identified with the osmotic potential defined above.

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[3] The above terms and their definitions relating to soil water are essentially those recommended by a committee of the International Society of Soil Science and published in Bulletin 23 (1963, p. 7-10) of that society. Some editorial changes have been made following comments received from a number of soil physicists in response to an inquiry by the SSSA Committee on Terminology. Because of the strong divergence of opinion expressed by the respondents, the Terminology Committee is listing the terms without approval or disapproval, but with the recommendation that society members express their opinion to the Editor-in-Chief or to the next committee chairman.

toposaic – A photomap on which topographic or terrain-form lines are shown, as on standard topographic quadrangles. See photomap and planisaic.

toposequence – A sequence of related soils that differ, one from the other, primarily because of topography as a soil-formation factor. See clinosequence.

topsoil – (i) The layer of soil moved in cultivation. See surface soil. (ii) The A horizon. (iii) The A1 horizon. (iv) Presumably fertile soil material used to topdress roadbanks, gardens, and lawns.

total potential (of soil water) – See soil water.

total pressure – See soil water.

trace elements – (Obsolete) See micronutrient.

traffic pan – See pan, pressure or induced.

transitional soil – A soil with properties intermediate between those of two different soils and genetically related to them.

transported soil – (Obsolete) Any soil which was formed on unconsolidated sedimentary rocks.

truncated – Having lost all or part of the upper soil horizon or horizons.

tuff – Volcanic ash usually more or less stratified and in various states of consolidation.

tundra – A level or undulating treeless plain characteristic of arctic regions.

Tundra soils – (i) Soils characteristic of tundra regions. (ii) A zonal great soil group consisting of soils with dark-brown peaty layers over grayish horizons mottled with rust and having continually frozen substrata; formed under frigid, humid climates, with poor drainage, and native vegetation of lichens, moss, flowering plants, and shrubs.

type, soil – See soil type.

U

ultimate particles – Individual soil particles after a standard dispersing treatment.

underground runoff (seepage) – Water flowing toward stream channels after infiltration into the ground.

undifferentiated soil groups – Soil mapping units in which two or more similar taxonomic soil units occur, but not in a regular geographic association. For example, the steep phases of two or more similar soils might be shown as a unit on a map because topography dominates the properties. See soil association and soil complex.

unsaturated flow – The movement of water in a soil which is not filled to capacity with water.

upper plastic limit – See liquid limit.

urban land – Areas so altered or obstructed by urban works or structures that identification of soils is not feasible. A miscellaneous land type.

V

value, color – The relative lightness or intensity of color and approximately a function of the square root of the total amount of light. One of the three variables of color. See Munsell color system, hue, and chroma.

variant – See soil variant.

varnish – See desert varnish.

varve – A distinct band representing the annual deposit in sedimentary materials regardless of origin and usually consisting of two layers, one a thick, light-colored layer of silt and fine sand and the other a thin, dark-colored layer of clay.

very coarse sand – See soil separates and soil texture.

very fine sand – See soil separates and soil texture.

very fine sandy loam – See soil texture.

volcanic-ash land – Areas of volcanic ash so recently deposited that the ash is essentially unmodified and shows little or no evidence of soil development. The areas have almost no vegetation on them. A miscellaneous land type.

W

wasteland – Land not suitable for, or capable of, producing materials or services of value. A miscellaneous land type.

water conductivity – See soil water.

water content – See soil water.

waterlogged – Saturated with water.

water-retention curve – See moisture-release curve and moisture-retention curve.

water-stable aggregate – A soil aggregate which is stable to the action of water such as falling drops, or agitation as in wet-sieving analysis.

water table – The upper surface of ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

water table, perched – The water table of a saturated layer of soil which is separated from an underlying saturated layer by an unsaturated layer.

weathering – All physical and chemical changes produced in rocks, at or near the earth's surface, by atmospheric agents.

wild flooding – See irrigation methods.

wilting coefficient – (Obsolete) A calculated value of the approximate wilting point or permanent wilting percentage. Calculated as follows:

$$\text{wilting coefficient} = \frac{\text{hygroscopic coefficient}}{0.68}$$

or,

$$\text{wilting coefficient} = \frac{\text{moisture equivalent}}{1.84}$$

wilting point – Same as "permanent wilting percentage" as defined in standard plant physiology texts. See fifteen-atmosphere percentage and fifteen-bar percentage.

windbreak – A planting of trees, shrubs, or other vegetation, usually perpendicular or nearly so to the principal wind direction, to protect soil, crops, homesteads, roads, etc., against the effects of winds, such as wind erosion and the drifting of soil and snow.

X

xerophytes – Plants that grow in or on extremely dry soils or soil materials.

Y

yield, sustained – A continual annual, or periodic, yield of plants or plant material from an area; implies management practices which will maintain the productive capacity of the land.

Z

zeta potential – See electrokinetic potential.

zonal soil – (i) A soil characteristic of a large area or zone. (ii) One of the three primary subdivisions (orders) in soil classification as used in the United States. See classification, soil.

zymogenous flora – Organisms found in soils in large numbers immediately following the addition of readily decomposable organic materials.

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